Status of the MIPP NuMI Target Data Analysis

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NuMI-X Meeting

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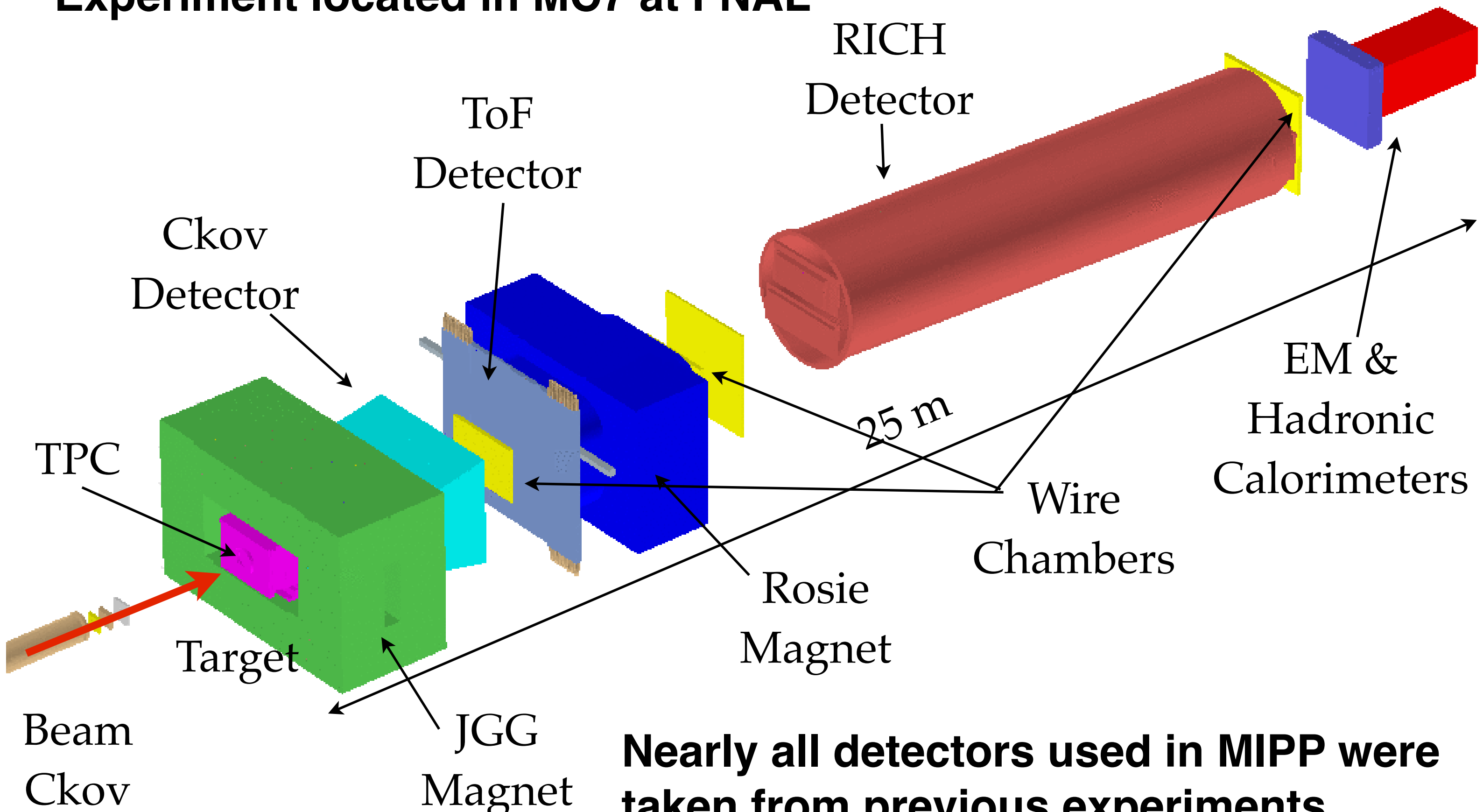
Argonne NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Main Injector Particle Production (MIPP) Experiment

Experiment located in MC7 at FNAL



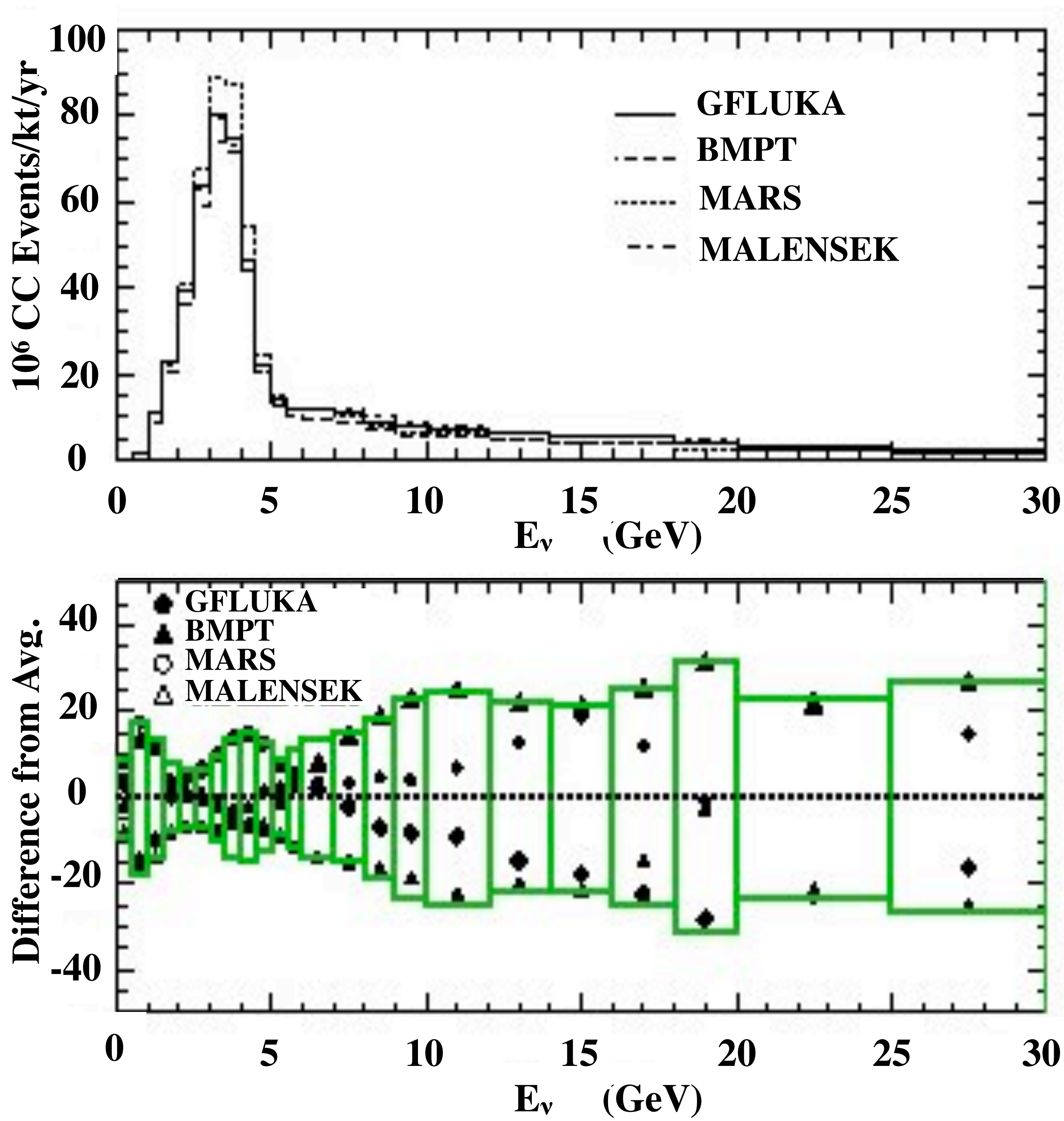
Nearly all detectors used in MIPP were taken from previous experiments.

- Goal: collect comprehensive hadron production cross-section data set with particle id using various beams and targets (thick and thin).

- Full acceptance spectrometer
- Two analysis magnets deflect in opposite directions
- TPC + 4 Drift Chambers + 2 PWCs

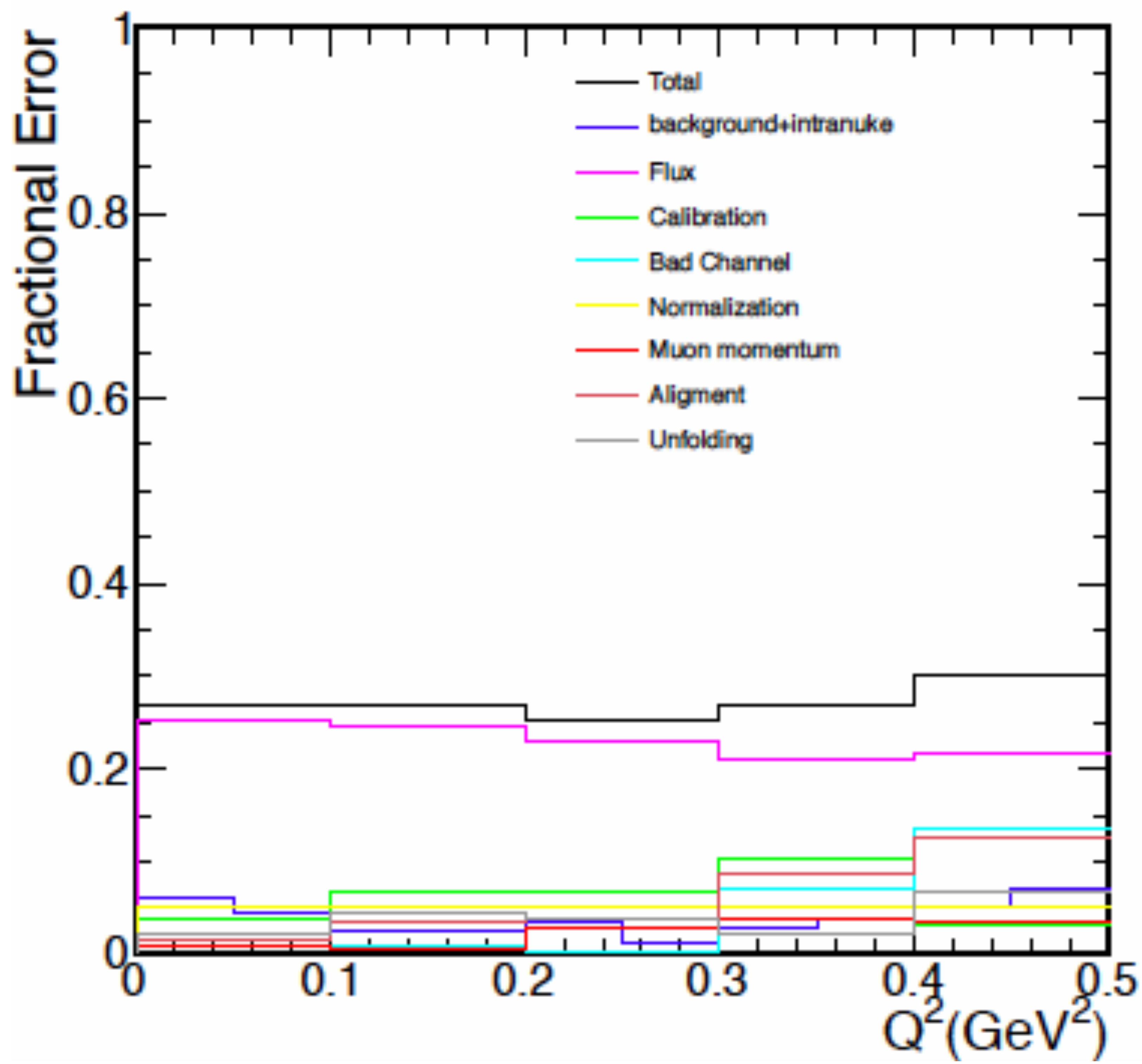
- Designed for excellent particle ID (PID) separation (2-3σ)

Some Motivation...



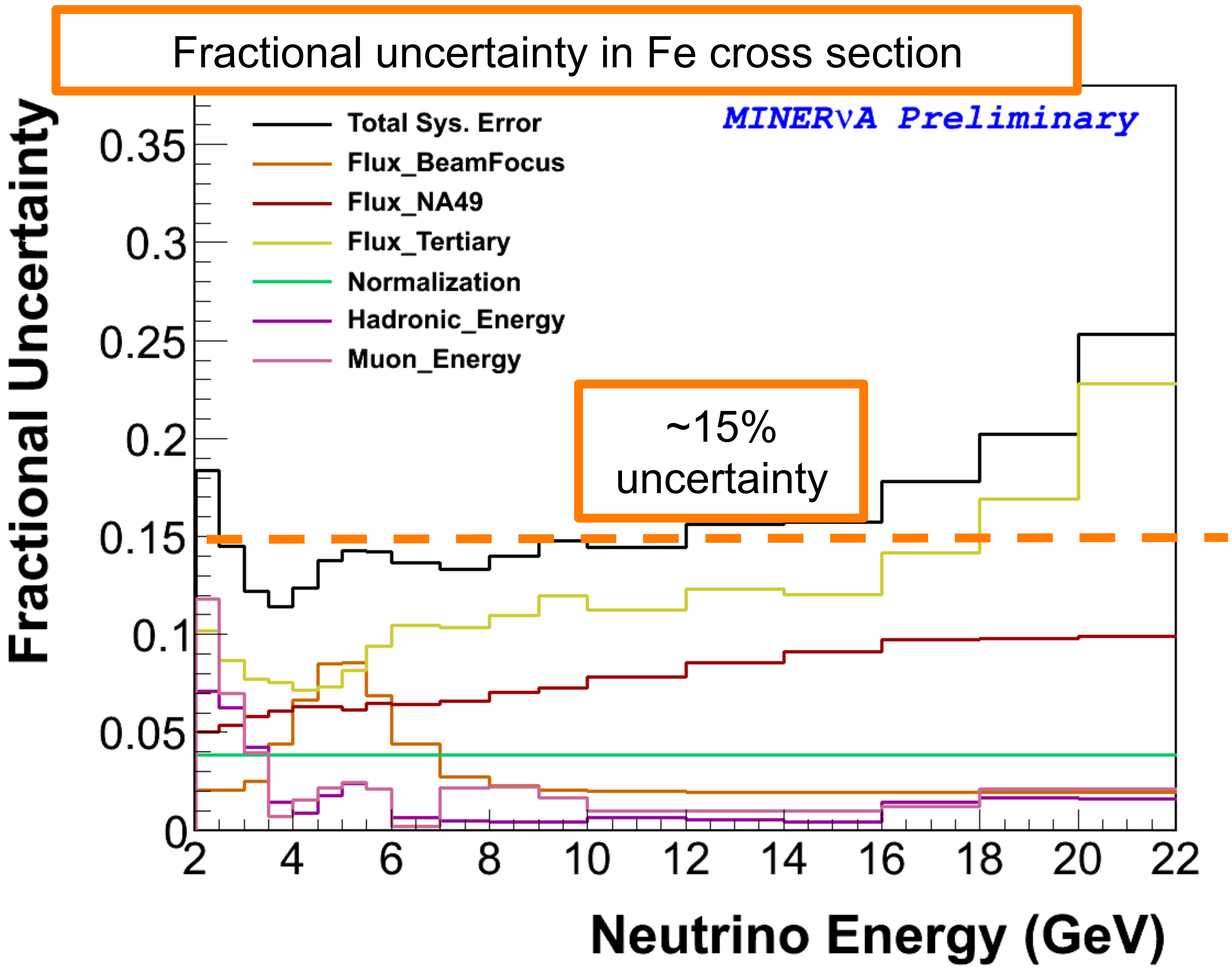
- Highly correlated models give predictions that differ up to 20%

Some Motivation...



NOνA NDOS $\sigma_{\nu\mu}$ CCQE Uncertainties

Some Motivation…

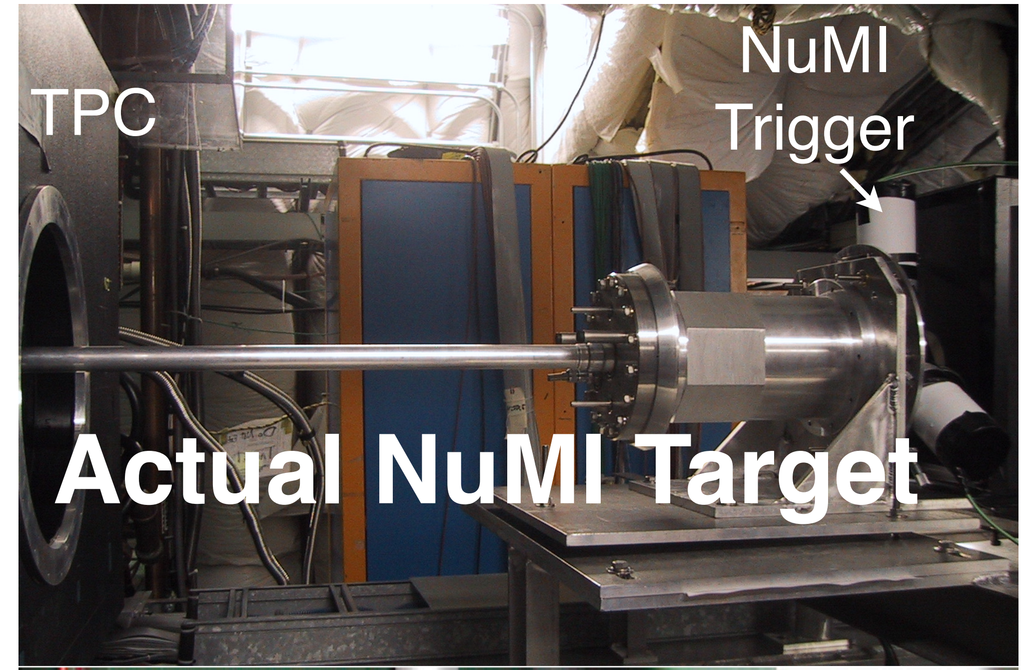


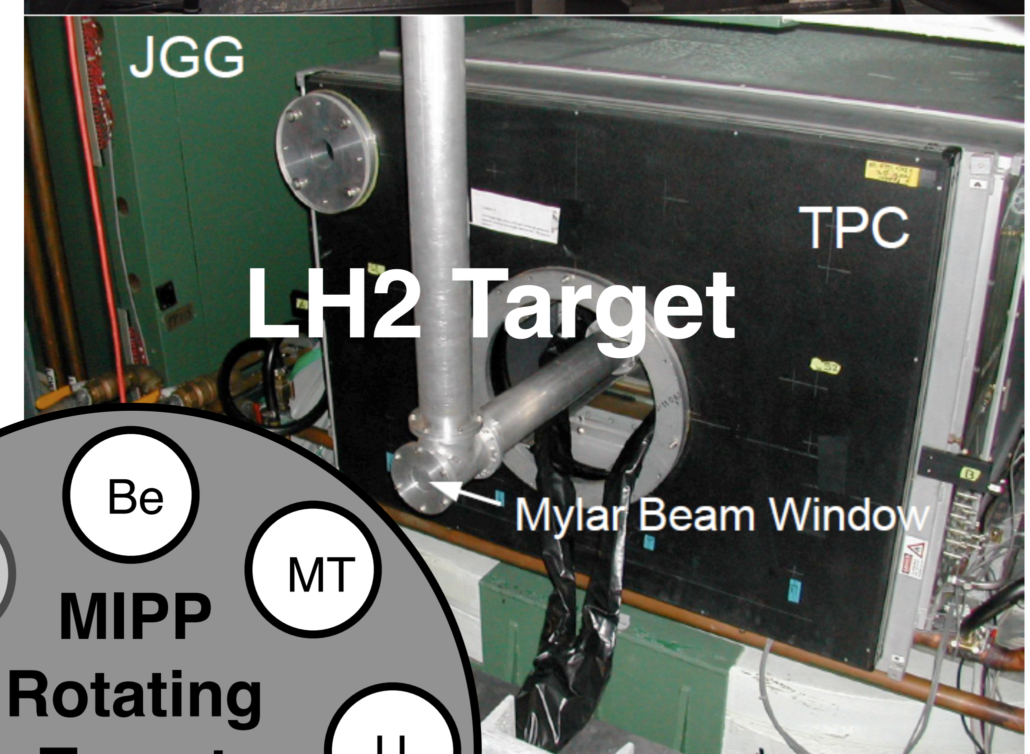
Steven Manly's NuFact 2013 MINERνA presentation

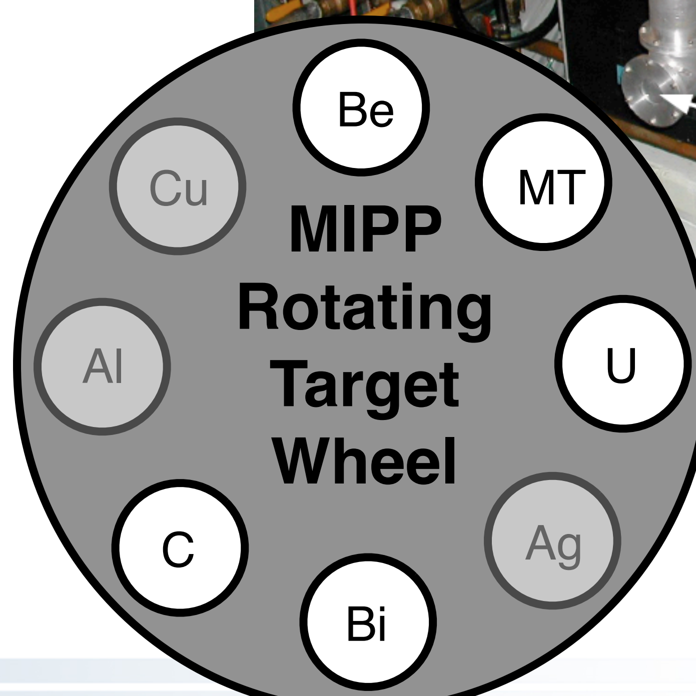
- Despite recent progress and measurements from hadron production experiments over the past 10+ years, we're still talking about 10-20% uncertainties in the hadron production off the NuMI target

Data Sets

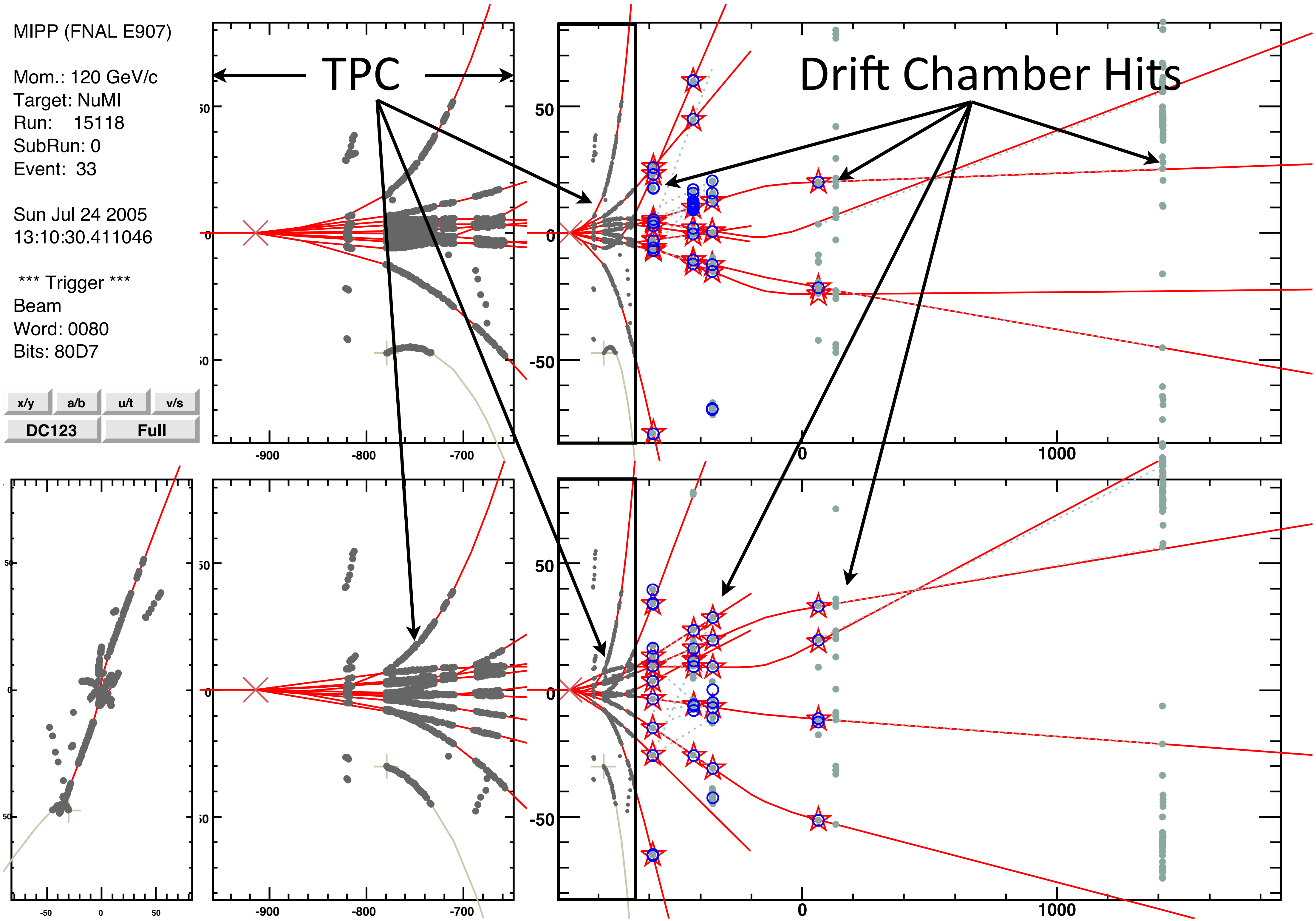
- MIPP began its physics run in December 2004 and ran until February 2006.
- DAQ rate was ~25 Hz, with MIPP receiving ~5% of MI beam.
- Data collected:
- ~1.6 x 10^6 events of Main Injector 120 GeV/c protons on a spare NuMI target.
- ~3.2 x 10^6 π's, K's and p's at 120, 60, 35 and 20 GeV/c on 1-2% λ_L C and Be targets.
    - ~7 x 10^6 π's, K's and p's at 85, 60, 20 and 5 GeV/c on 1% λ_L LH2 target.
    - ~4 x 10^6 π's, K's and p's at 35, 60 and 120 GeV/c on Bi and U targets.





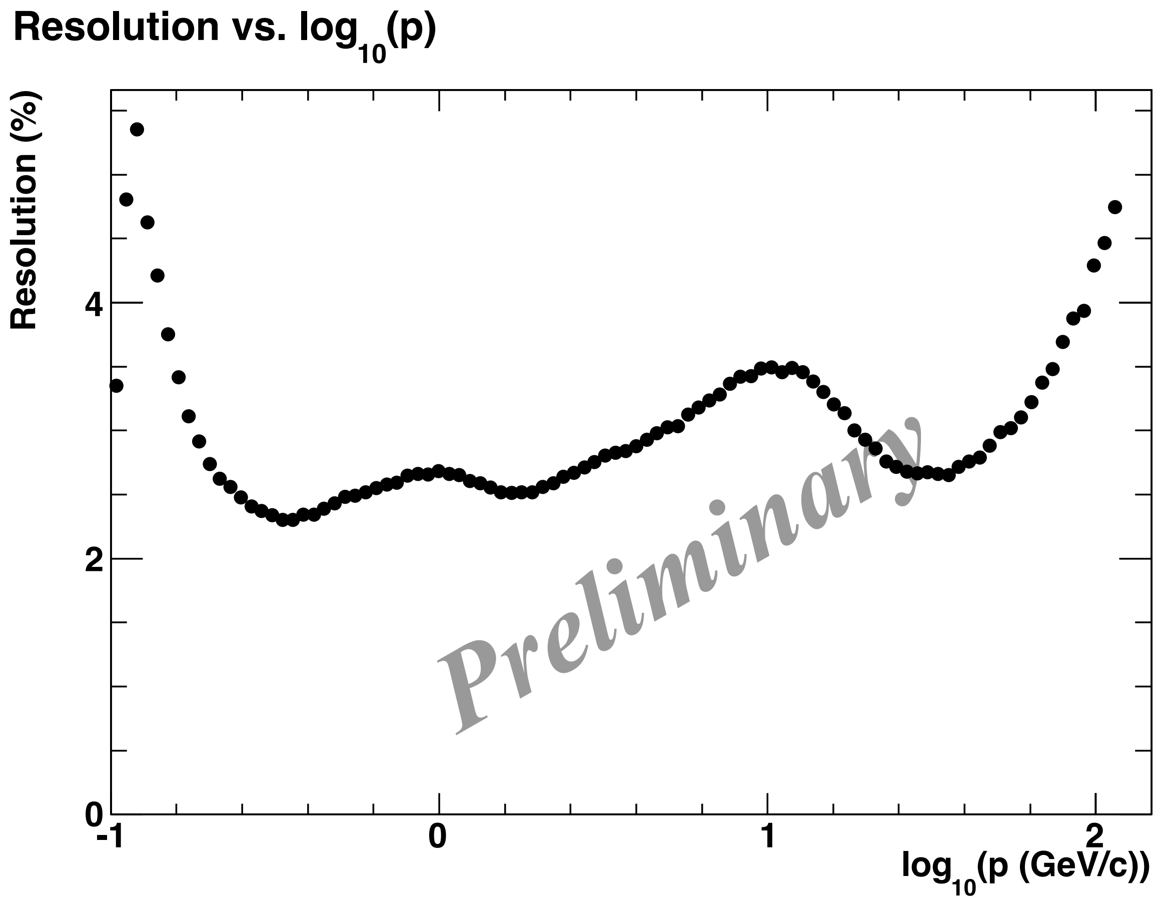


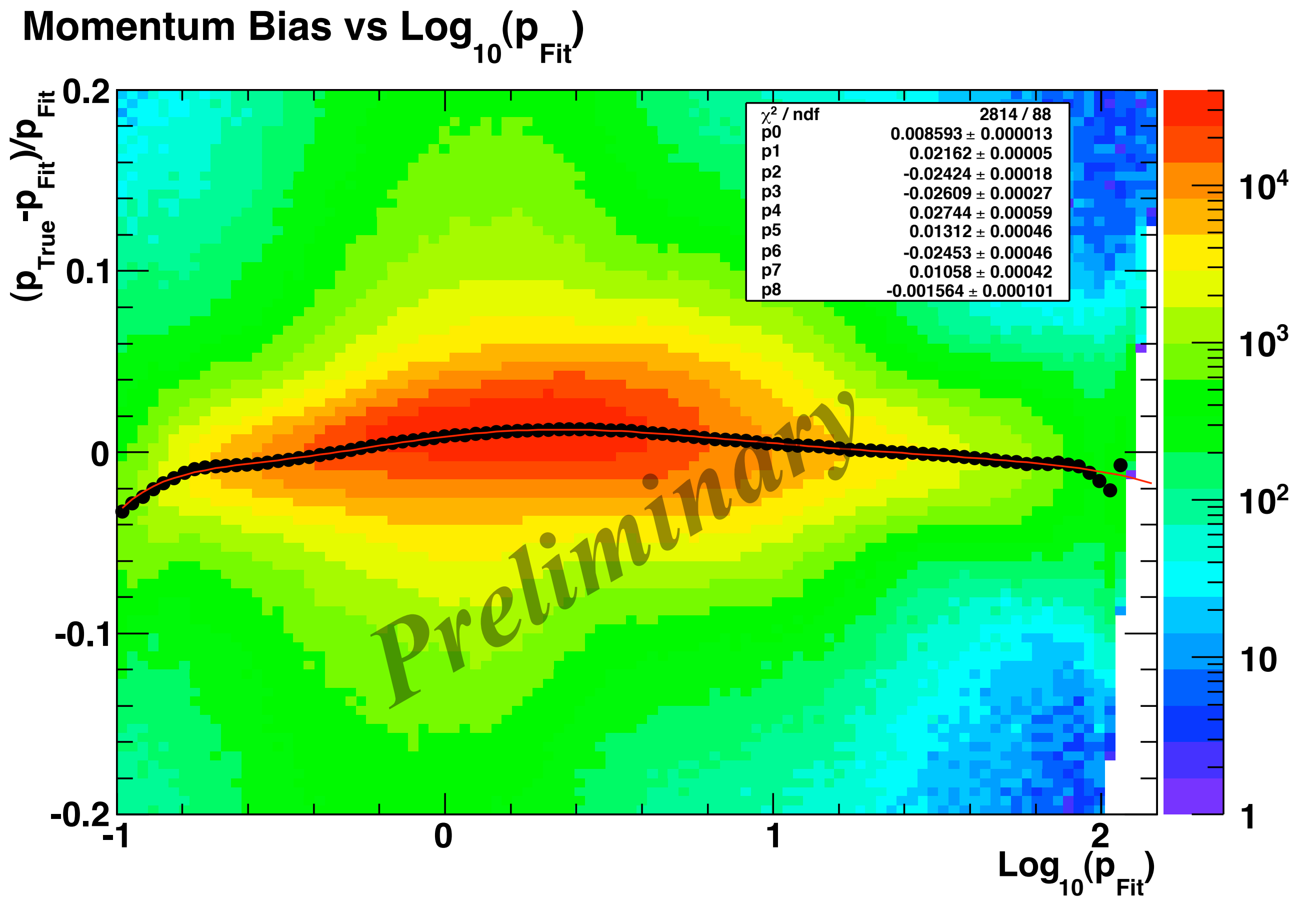
Global Track Reconstruction



TPC track segments are matched to downstream drift chamber hits, momentum is determined from bend in both magnets.

Momentum Resolution and Bias

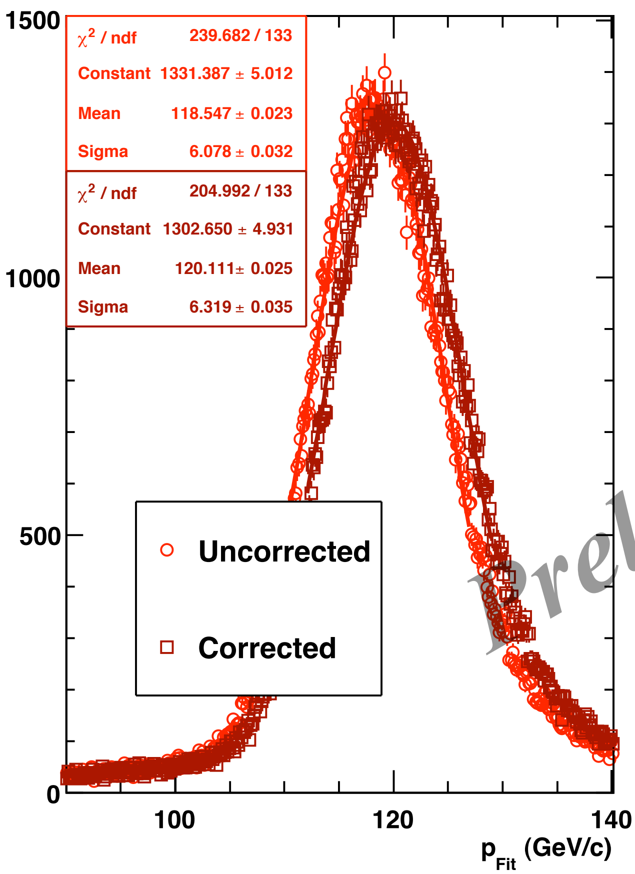




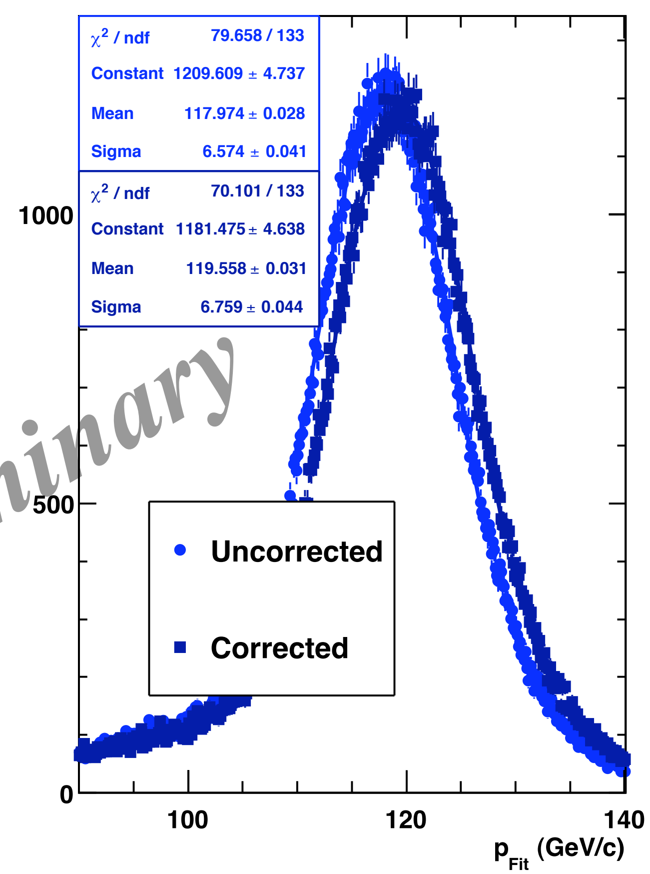
- Black points determined by fitting central peaks of slices of dp/p to Gaussian.
- Momentum resolution is < ~5%
- Bias < ~2%. Correction is applied and has a very small uncertainty.
- Transverse momentum resolution is < 0.02 GeV

Absolute Momentum Scale

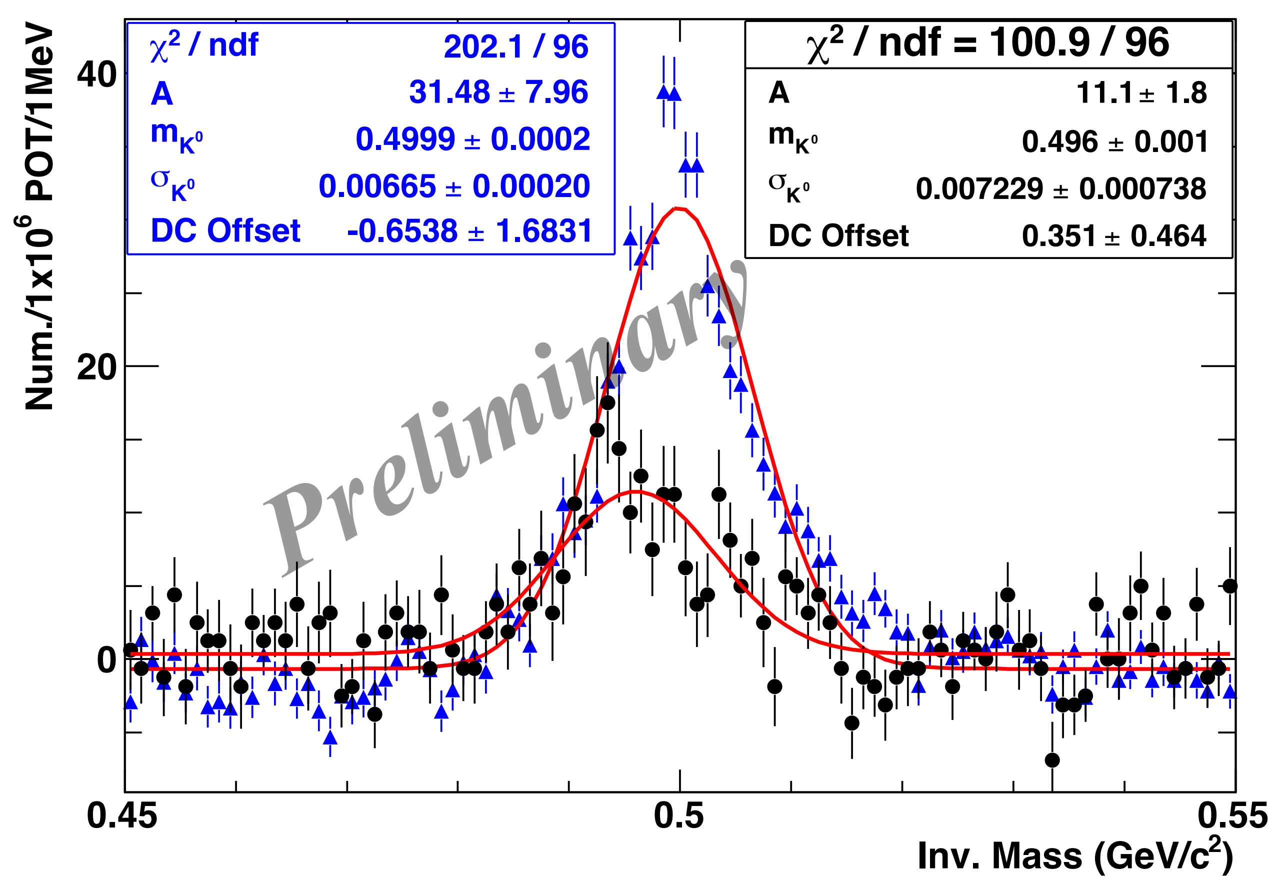
NuMI MC



NuMI Data



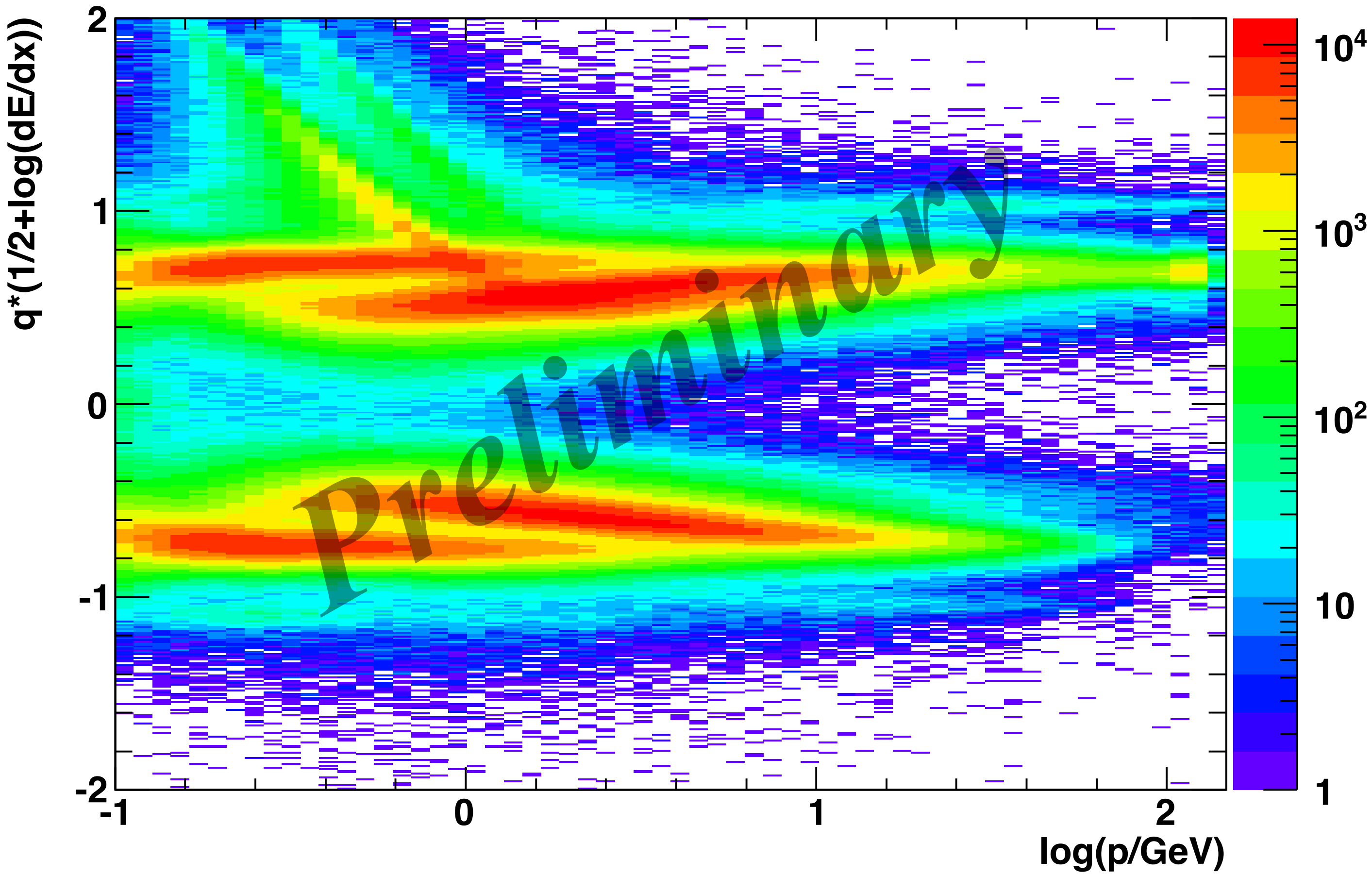
Bkg-Subtracted Inv. Mass Distribution, NuMI MC, dz Cut



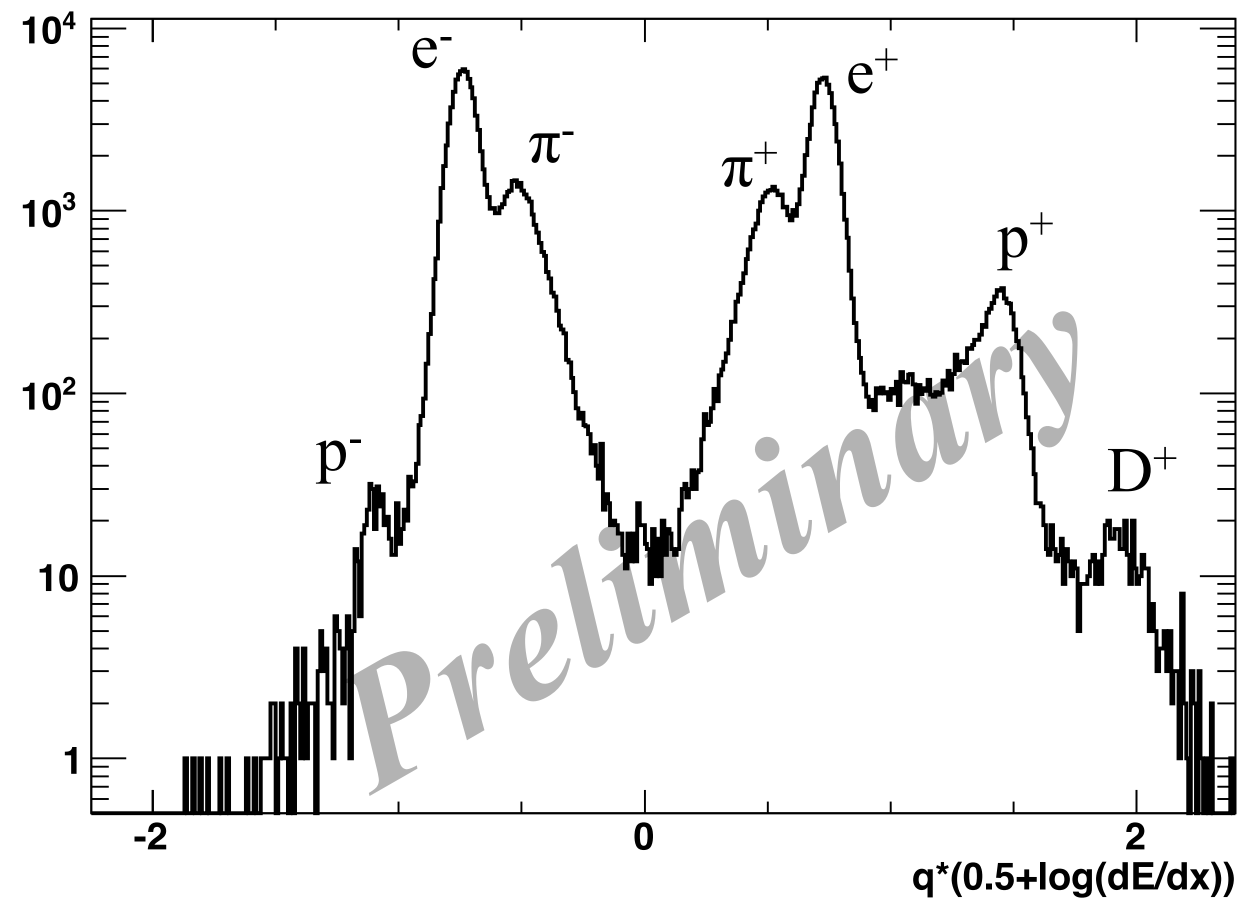
- After momentum bias correction, single proton beam data and MC agree.
- Reconstructed K^0 invariant mass using tracks with $p < 2$ GeV/c indicates systematic offset of ~-1%.

TPC PID Performance

TPC <dE/dx> vs. P, Full NuMI Data Set

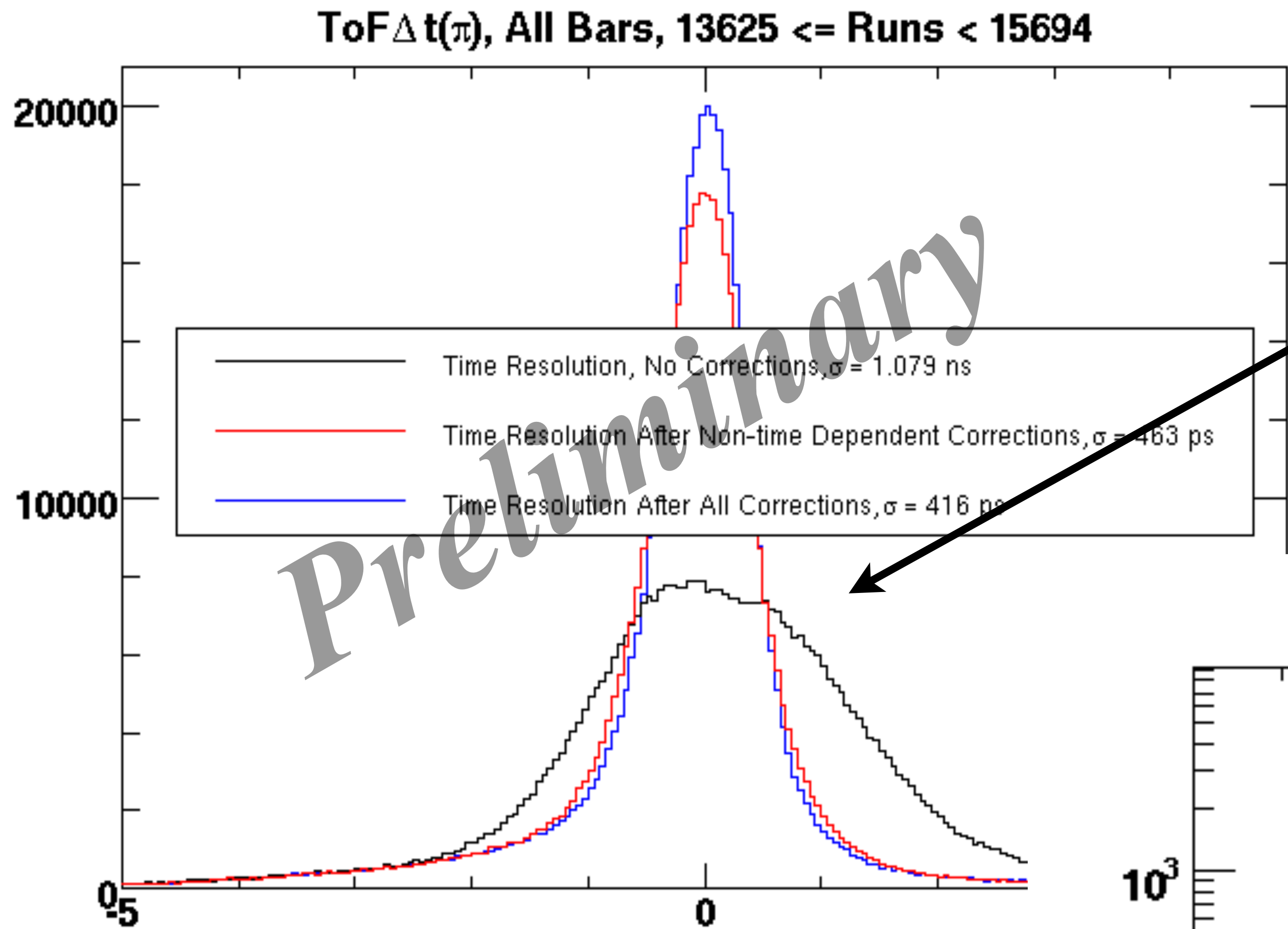


TPC <dE/dx> for 0.30 < P < 0.33 GeV/c

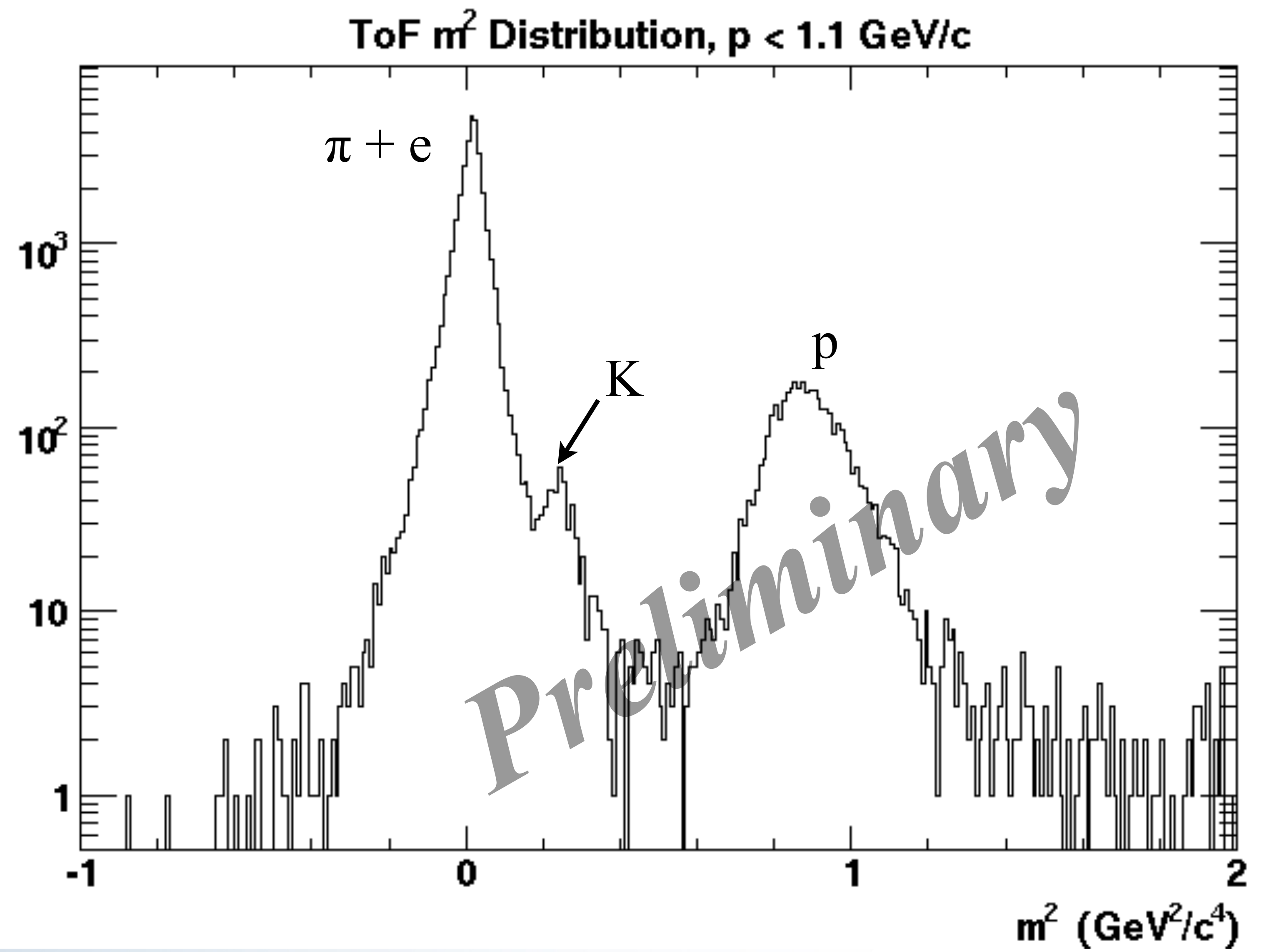


- TPC data are calibrated such that <dE/dx>(π) is 1 for p = 0.4 GeV/c and give expected Bethe-Bloch functional form.
- <dE/dx> resolution ~10%.
- Clean π, p separation between 0.2 and 1.2 GeV/c.

ToF PID Performance



Data-driven calibration improved timing resolution by about a factor of 2.5



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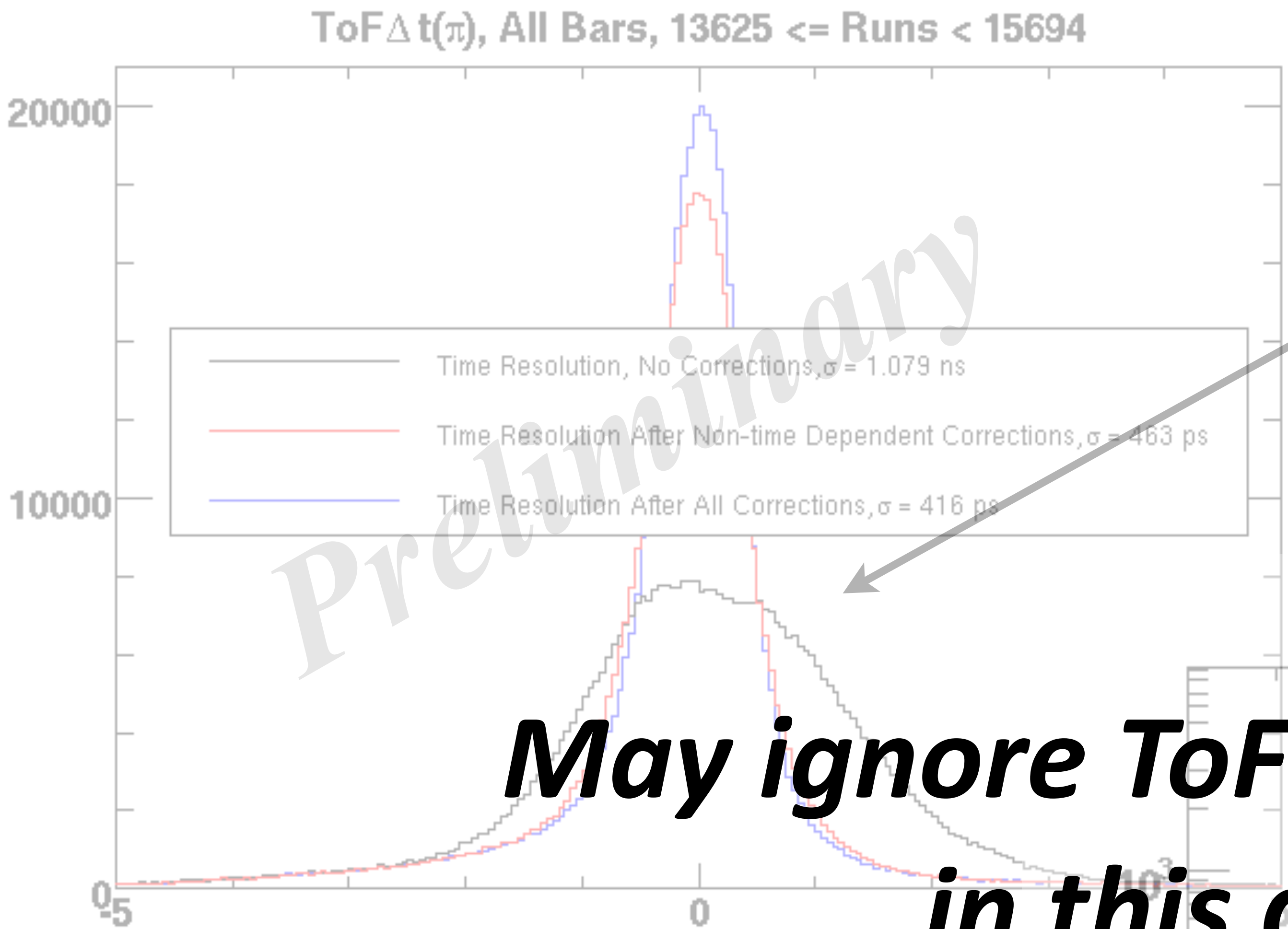

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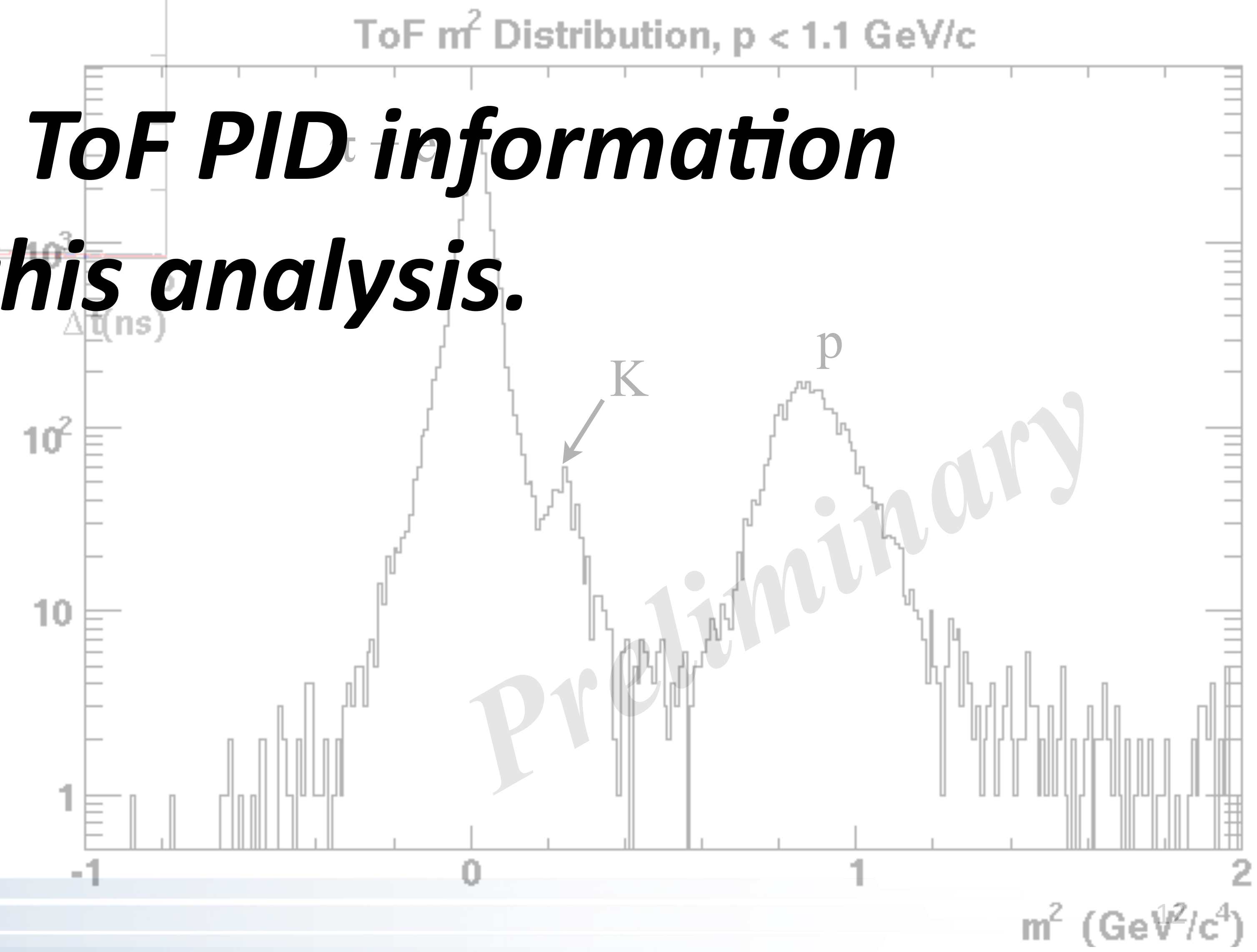
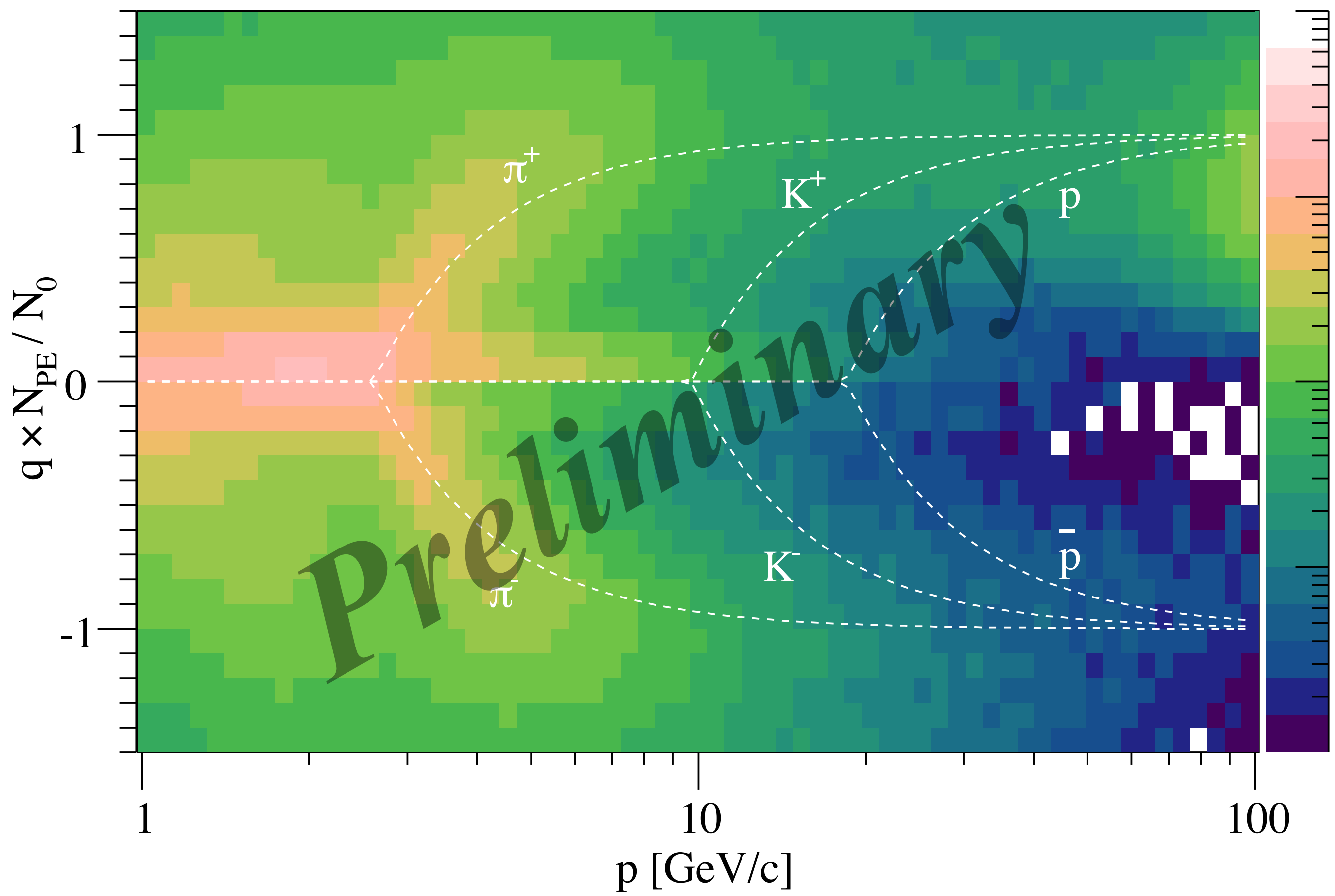
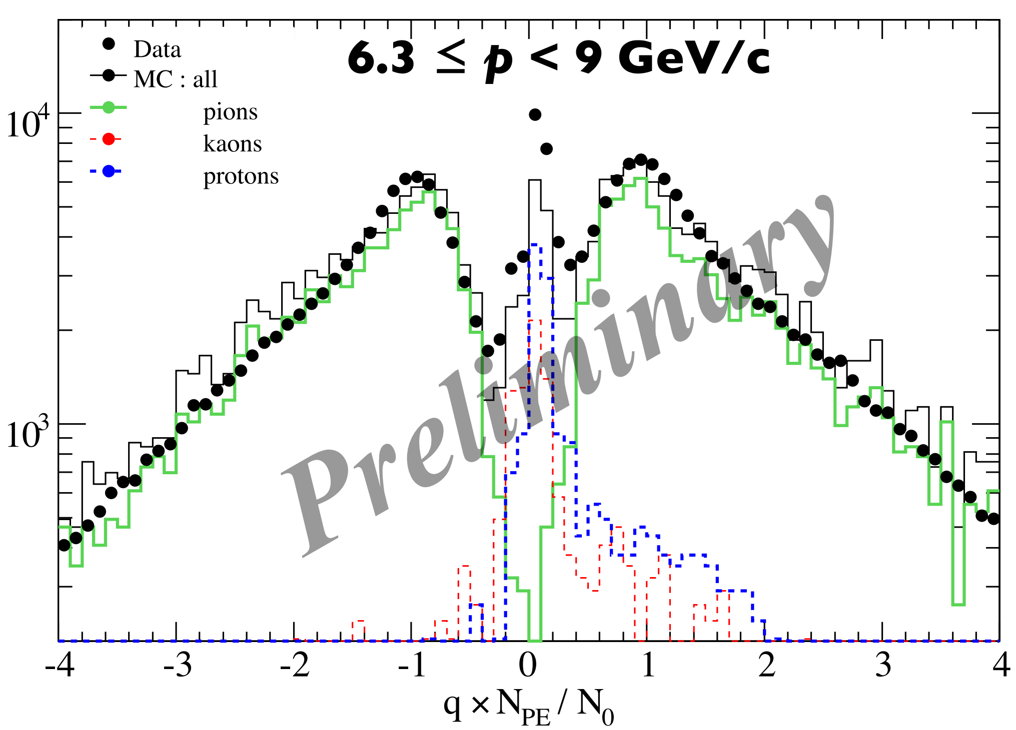


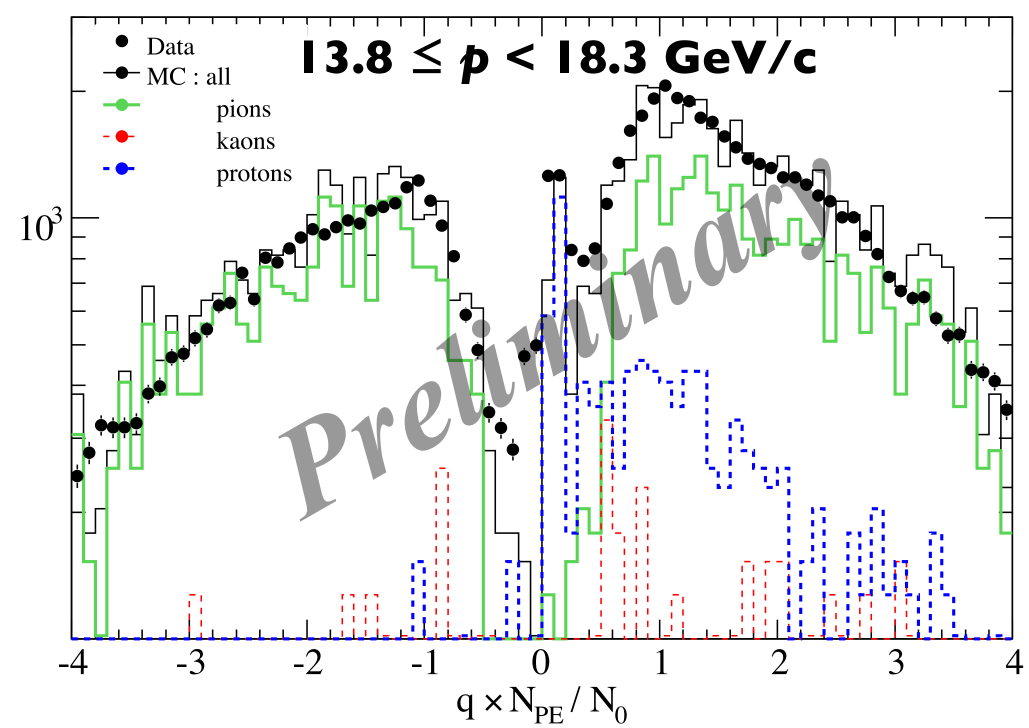
May ignore ToF PID information in this analysis.

Ckov PID Performance



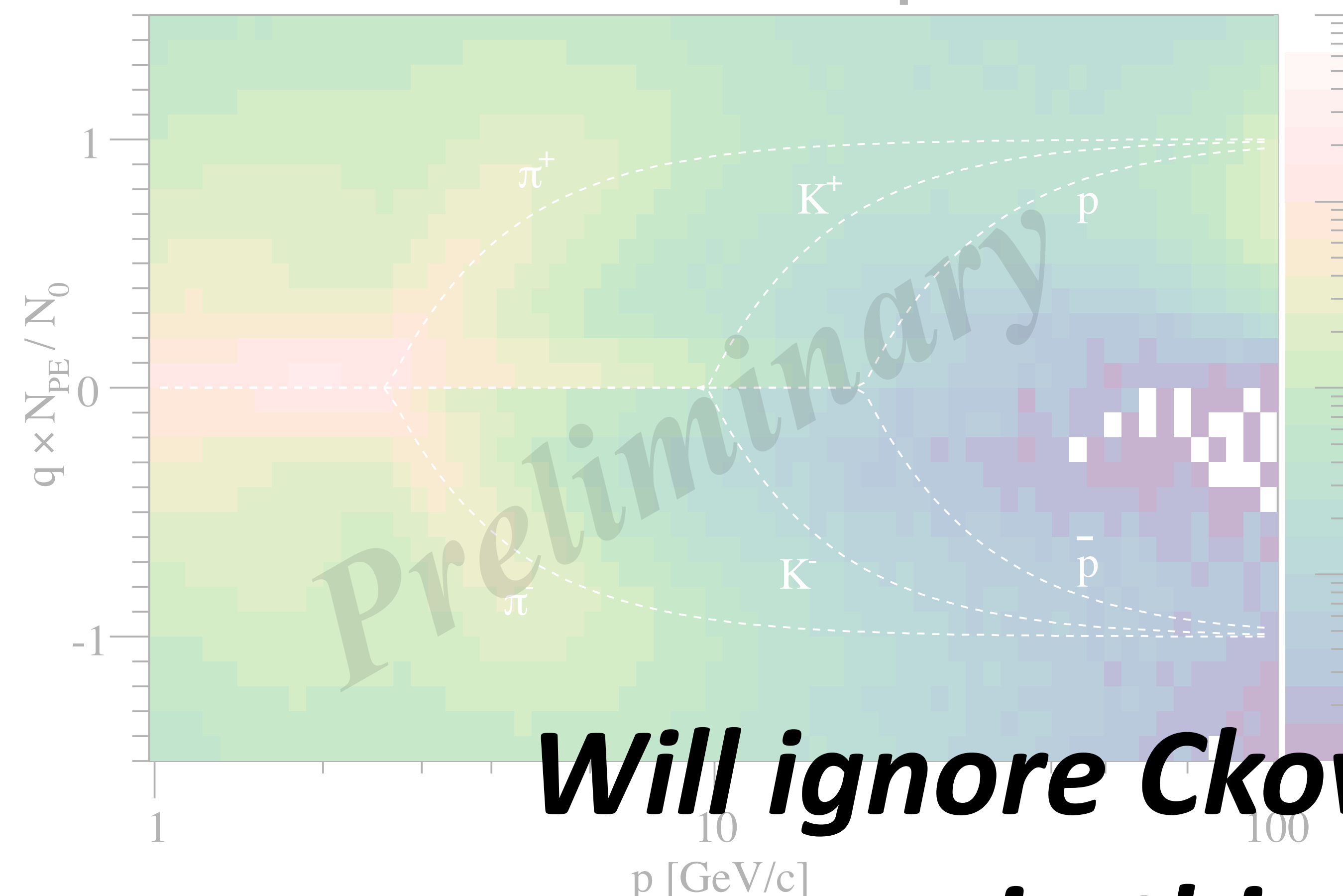
- Since all mirrors have a different response, each measurement of Npe is normalized to that of a β=1 particle.
- Pion "turn-on" clearly visible; proton "turn-on" also visible in slices of momentum.
- Shape of normalized response dist. in MC agrees very well with data.
- Data-driven calibration of 96 mirrors found detector response gives <10 pe/β=1 track.





- Must only consider "isolated" tracks passing through mirrors; reject ~50% of Ckov PID data.

Ckov PID Performance



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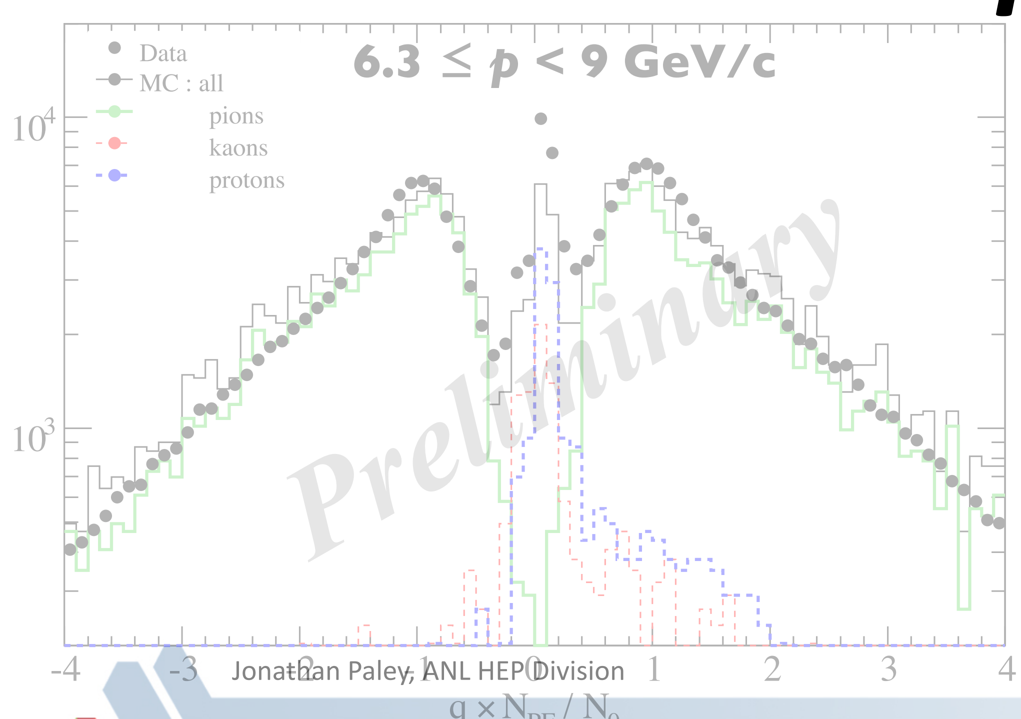
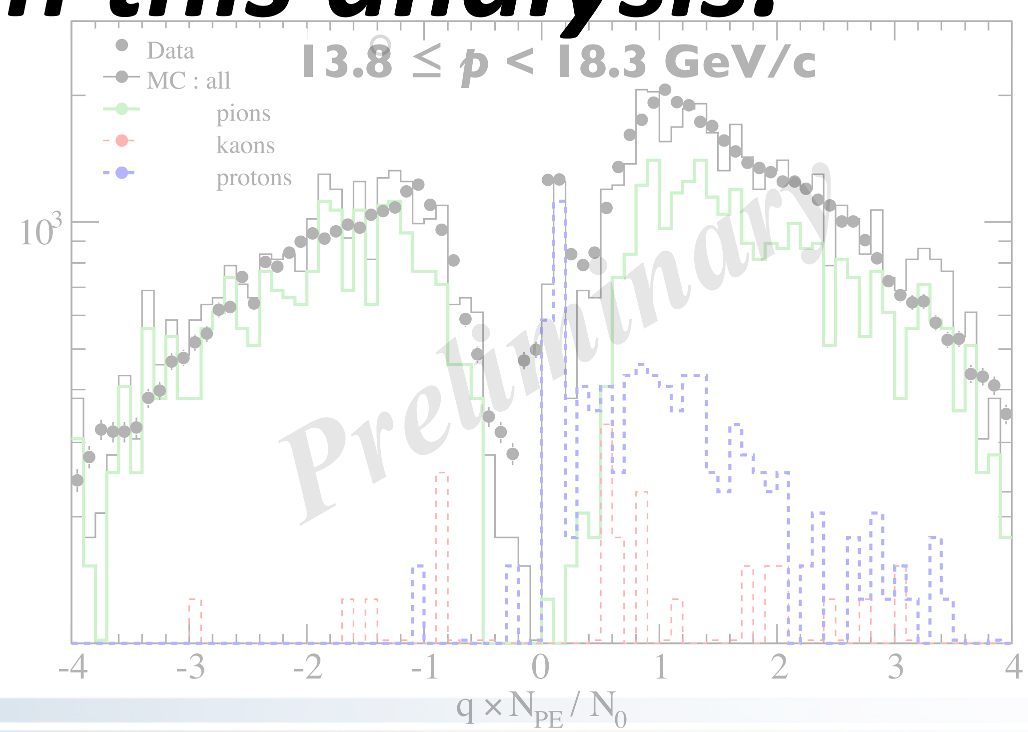
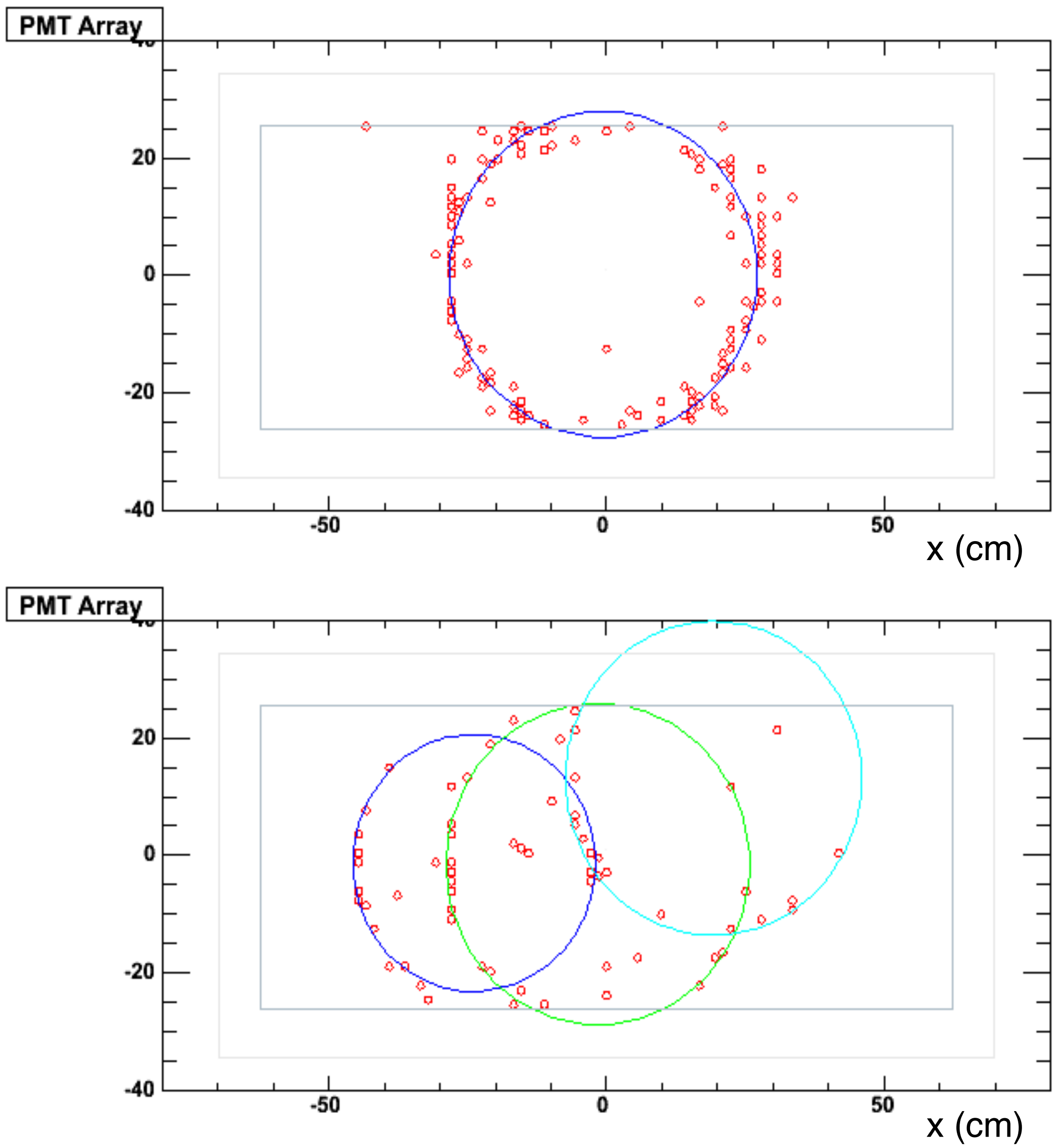
Will ignore Ckov PID Information in this analysis.

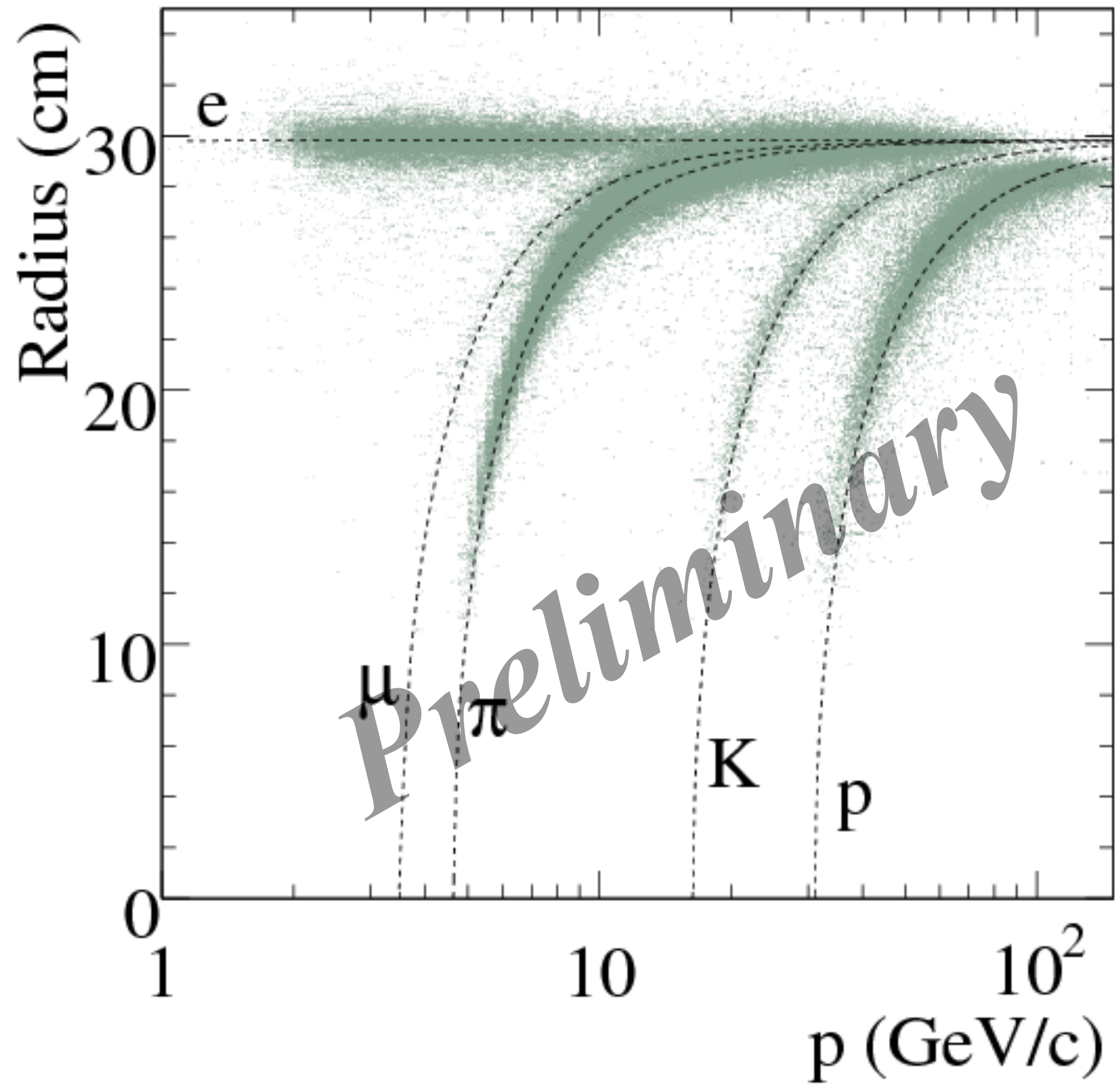




- Must only consider "isolated" tracks passing through mirrors; reject ~50% of Ckov **PID** data.

RICH PID Performance



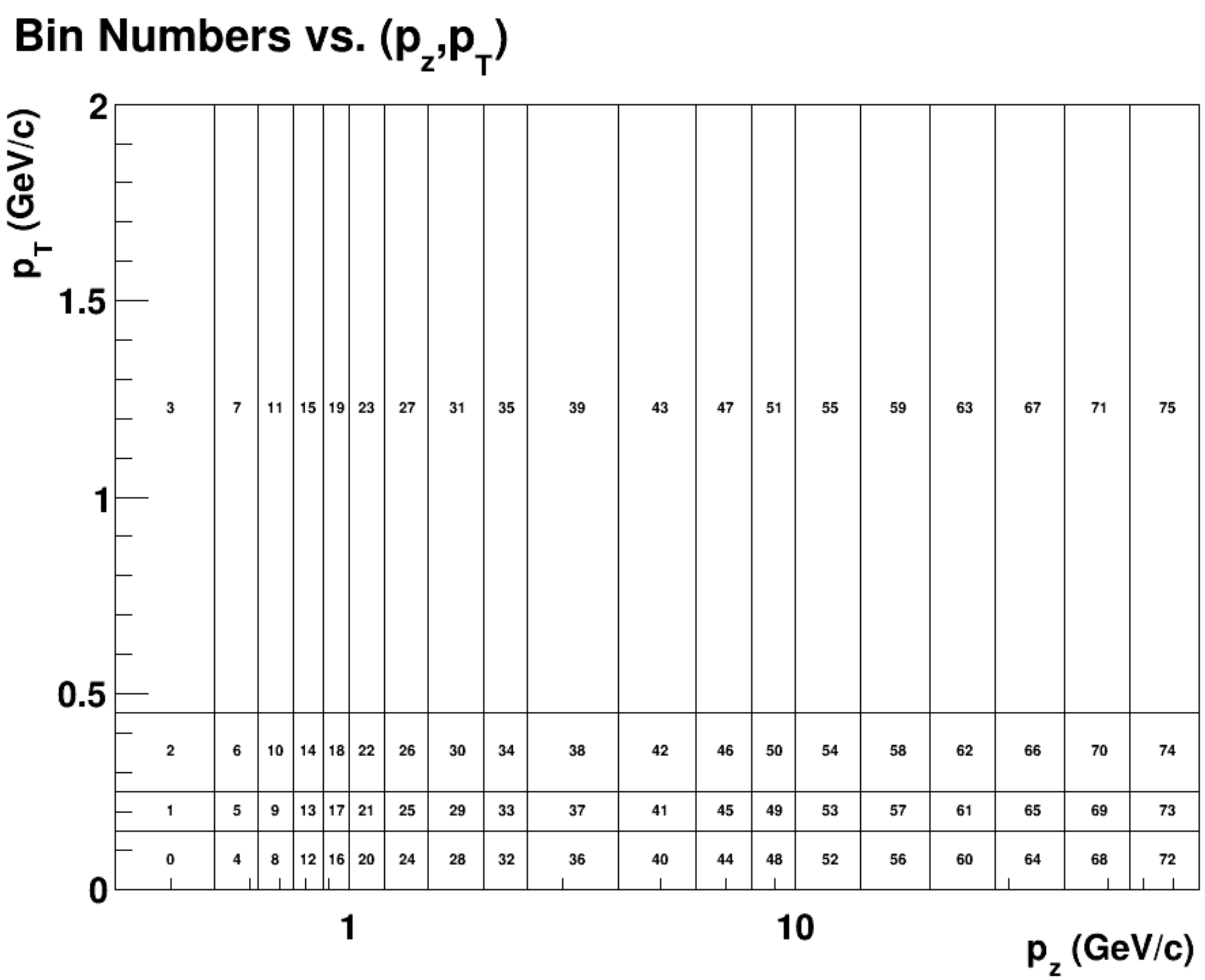


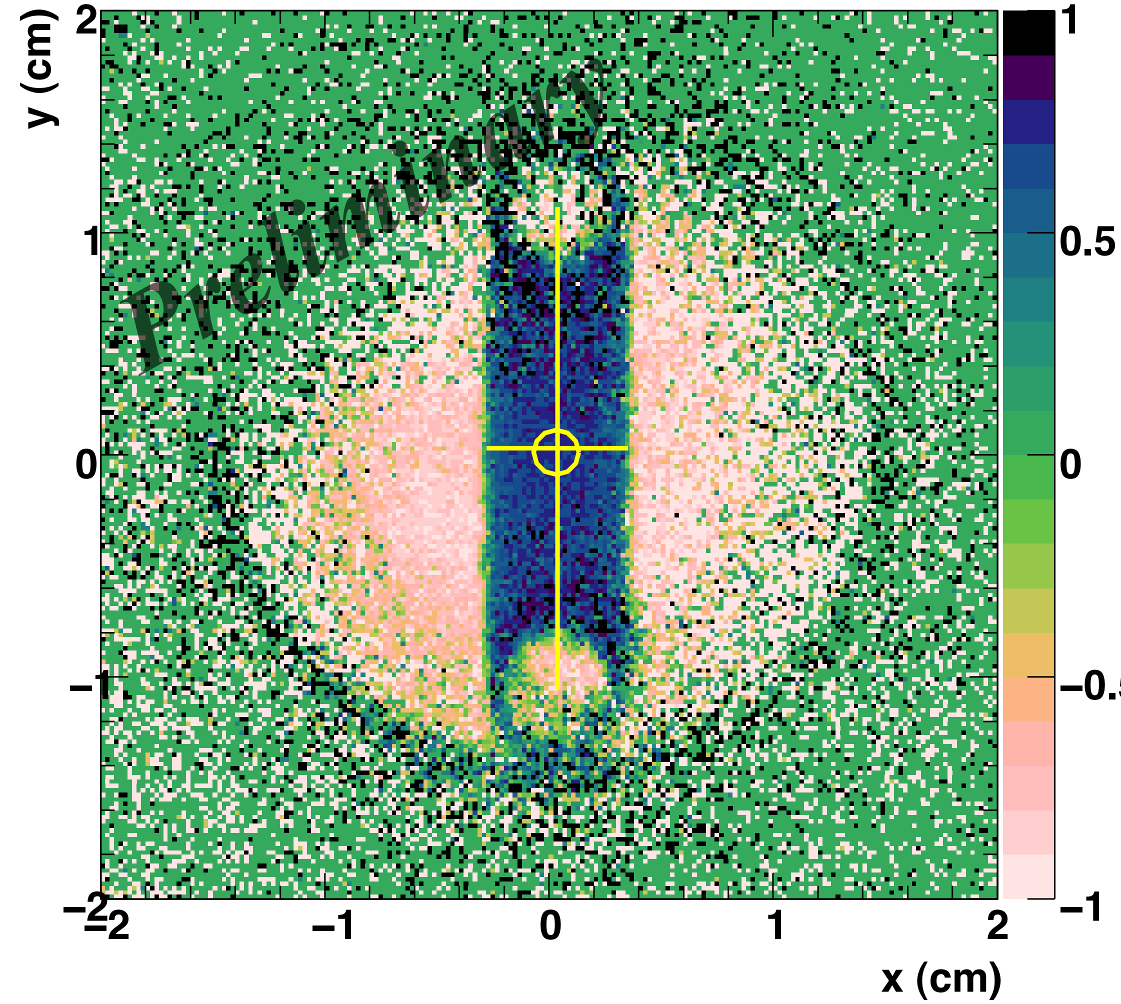
- Ckov light ring formed on array of ~2300 1/2" PMTs.
- Ring radius ~ Ckov angle ~ velocity.
- 3σ π/K and 3σ p/K separation up to 80 GeV/c

NuMI Target Analysis

NuMI Target Analysis

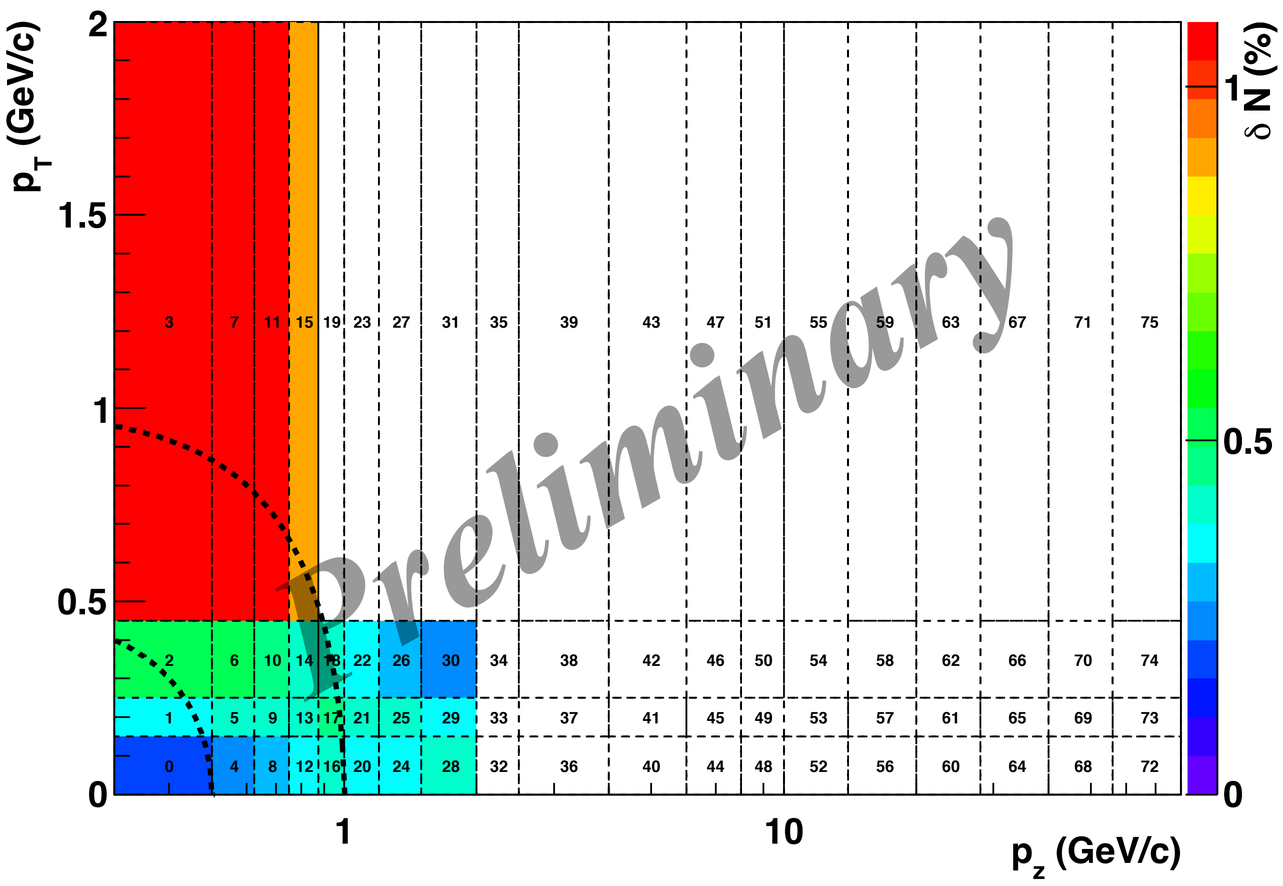
- Measure pion yield off surface of NuMI target (120 GeV/c p + NuMI).
- $N(\pi^{\pm})/POT$ binned in (p_z, p_T), currently we have 76 bins.



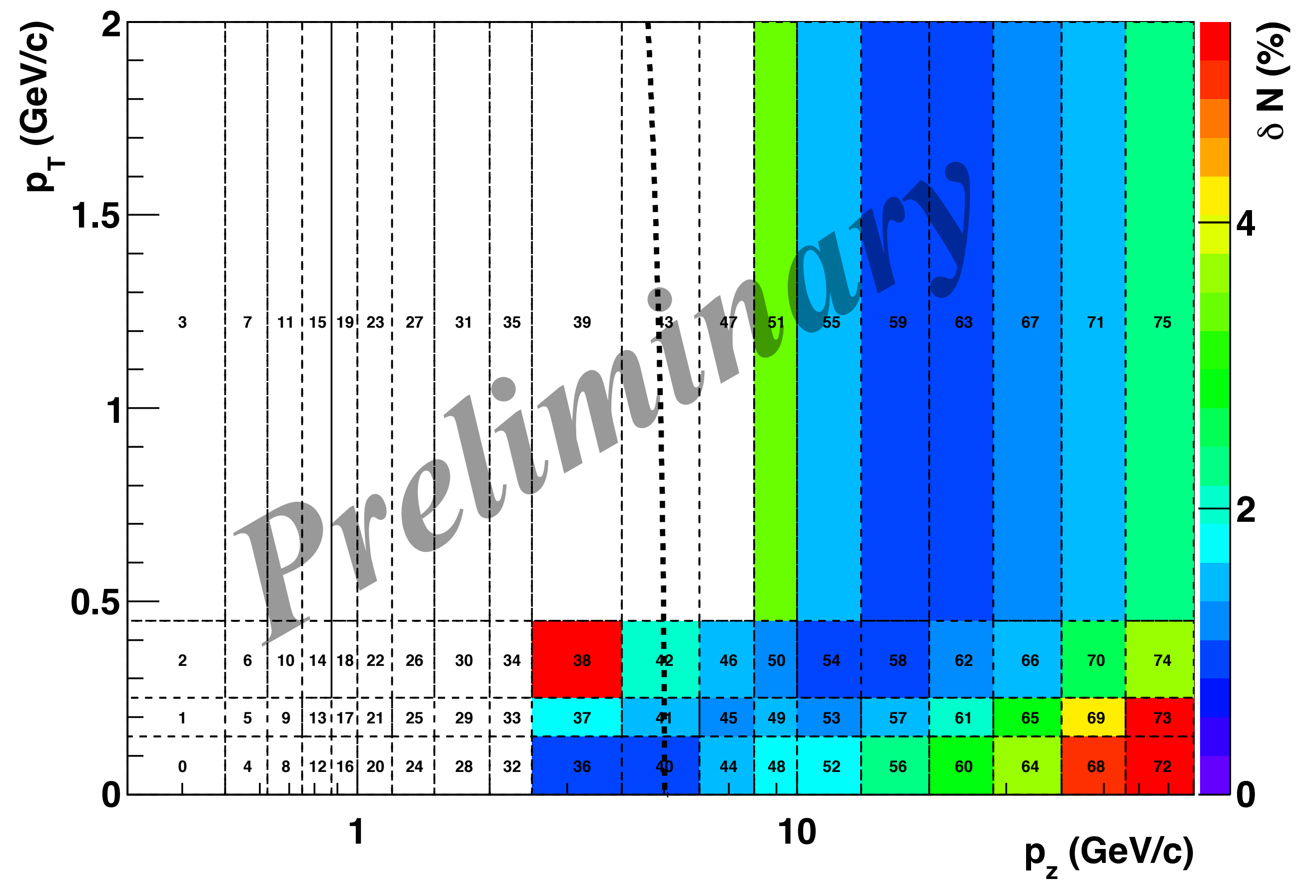


- Event selection finalized
- Will use TPC and RICH particle identification measurements; will investigate possibility of including ToF data

Estimated Statistical Uncertainties



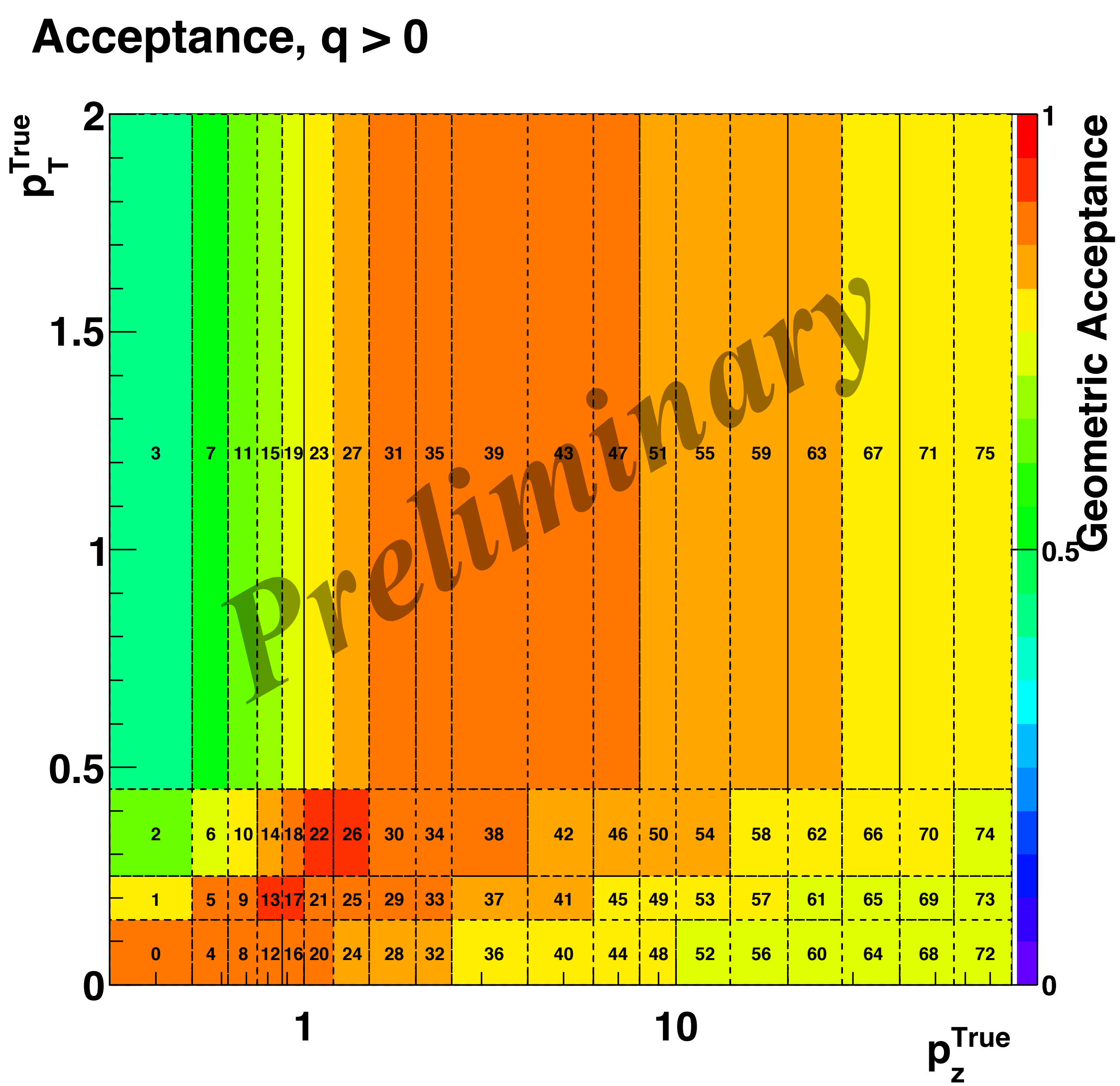
Maximum statistical uncertainty
based on number of TPC tracks.

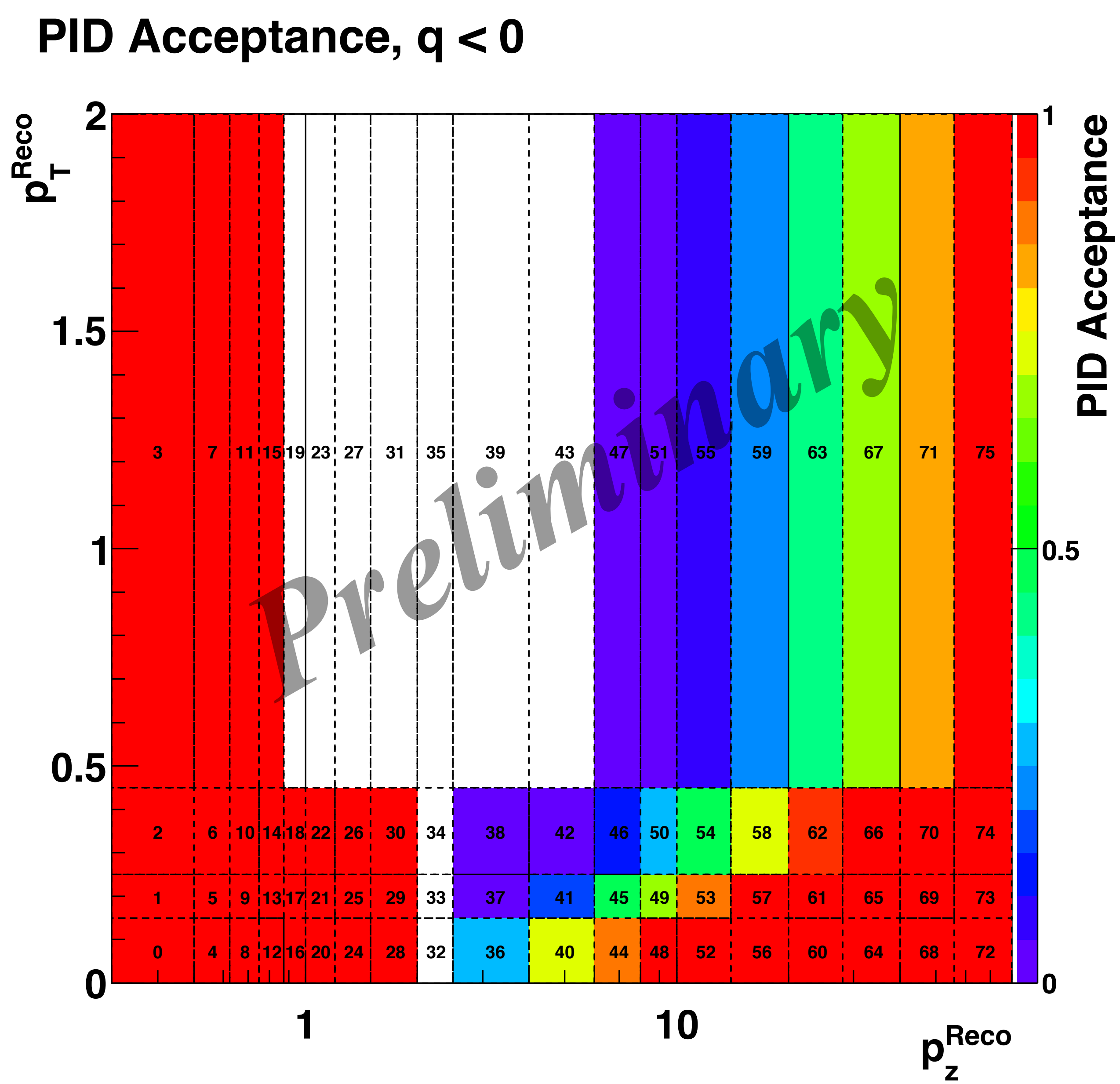


Maximum statistical uncertainty
based on tracks matched to RICH rings.

- To get an idea of how well we can do in each bin, we assume 70% of tracks that have PID information is a pion.
- Expected statistical uncertainties are below 6% everywhere for *positively charged* tracks with TPC and RICH PID information. Negatively charged tracks are slightly worse.

Acceptance Corrections





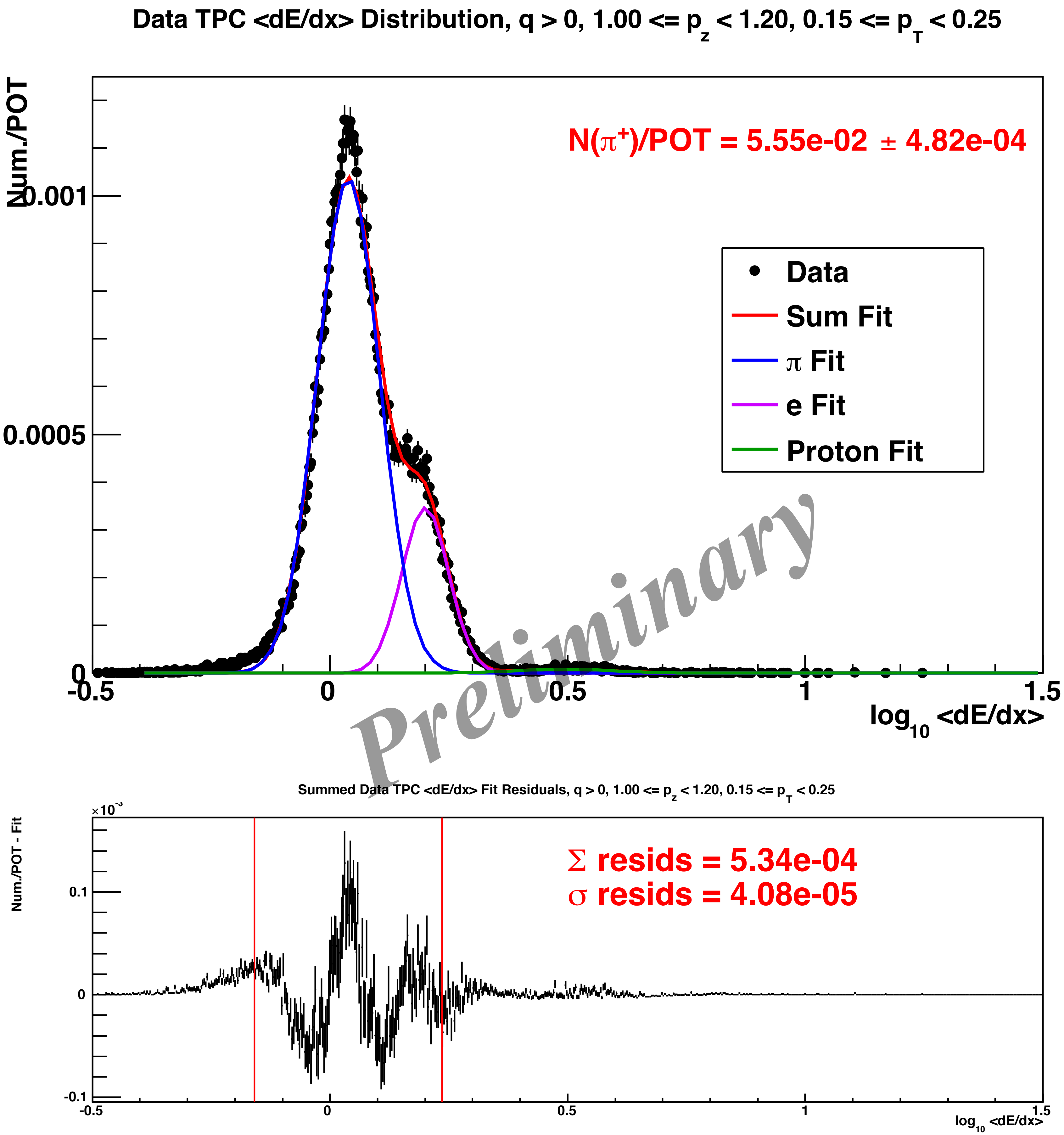
- Geometric acceptance (fraction of true particles matched to a reconstructed track) is typically 75-85%
- PID acceptance is the fraction of reconstructed tracks that made it into a PID detector. Acceptance for TPC tracks is 100% by definition.

TPC PID Measurements

- *log(<dE/dx>)* distributions appear to be Gaussian in bins of p_{TOT}, and "very" Gaussian in most (p_z,p_T) bins.
- Approach is to fit these distributions to sum of 4 Gaussians
- TPC fits: function is 3-Gaussian sum, kaons are negligible

$$N(x) = A_\pi \left(f_{e\pi} \exp(\frac{(x-x_e)^2}{2\sigma_e^2}) + \exp(\frac{(x-x_\pi)^2}{2\sigma_\pi^2}) + f_{p\pi} \exp(\frac{(x-x_p)^2}{2\sigma_p^2}) \right)$$

  - "x" = log(<dE/dx>)
  - $f_{e\pi} = A_e/A_\pi$, $f_{p\pi} = A_p/A_\pi$
  - widths are constrained to be "physical", means are constrained to be close to expected values from MC
- Positive and negative particle distributions are fit independently for now.



- $N(\pi)$ = integral of Gaussian corresponding to pion peak. Uncertainty derived from fit parameter uncertainties.

- The extent to which any non-Gaussian feature(s) of the distribution effects the $N(\pi)$ can be estimated by looking at the integral of the residuals over the range of the pion peak. Very small effect observed.

RICH PID Measurements

- These measurements can trivially be converted to m^2 distributions, but do not appear to be very Gaussian.

- Approach is to "cut and count". Split m^2 distribution in each (p_z,p_T) bin into three regions: 1 "mostly" signal + 2 "mostly background" sidebands.

$$N_\pi = \sum_i N_{\pi_i} \qquad \sigma_\pi^2 = \sum_i \sigma_{\pi_i}^2$$

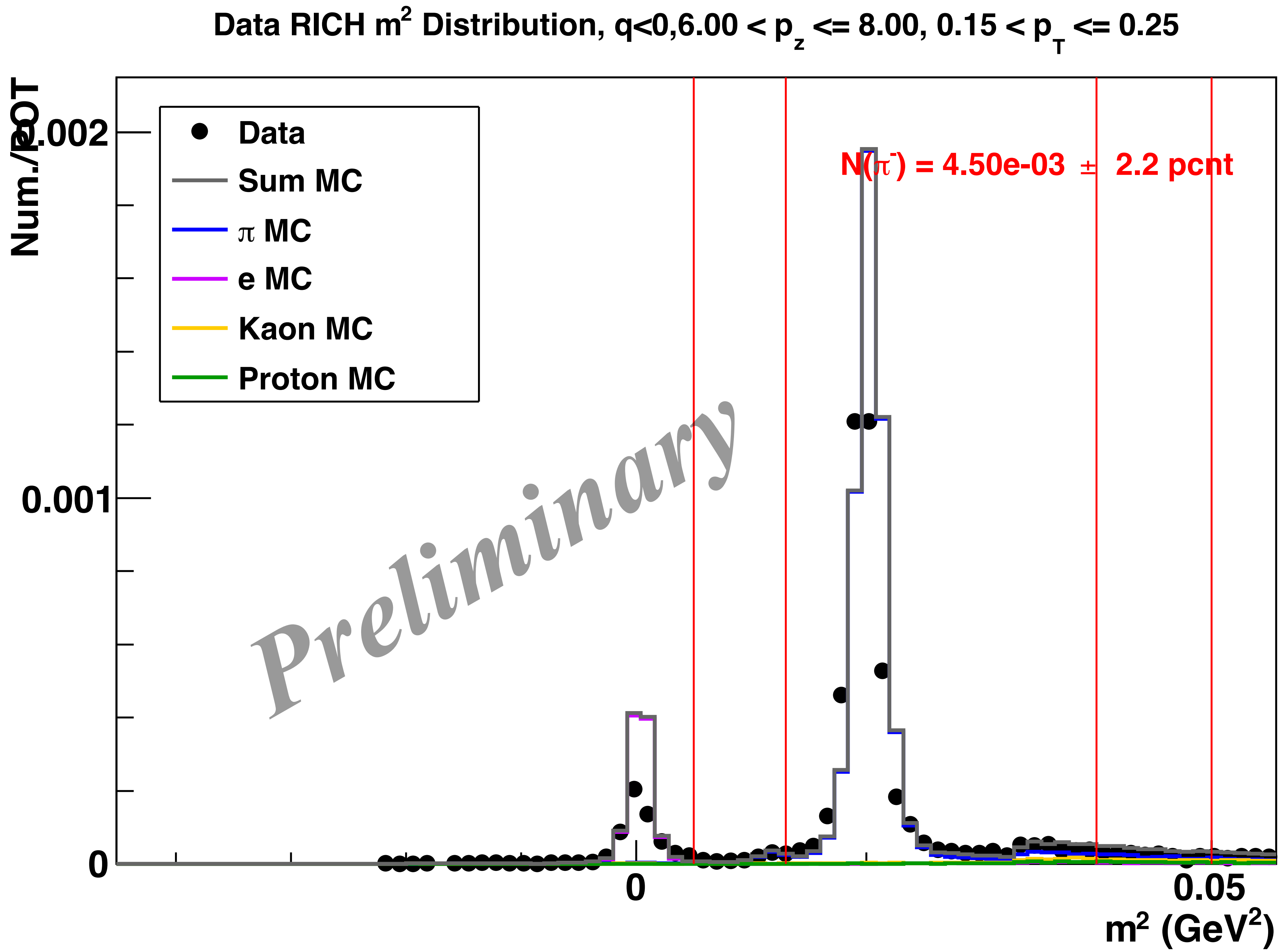
Data

$$N_{\pi_i} = N_i - b_i \bar{N}_i \qquad b_i = \frac{B_i}{\bar{S}_i + \bar{B}_i}$$

MC

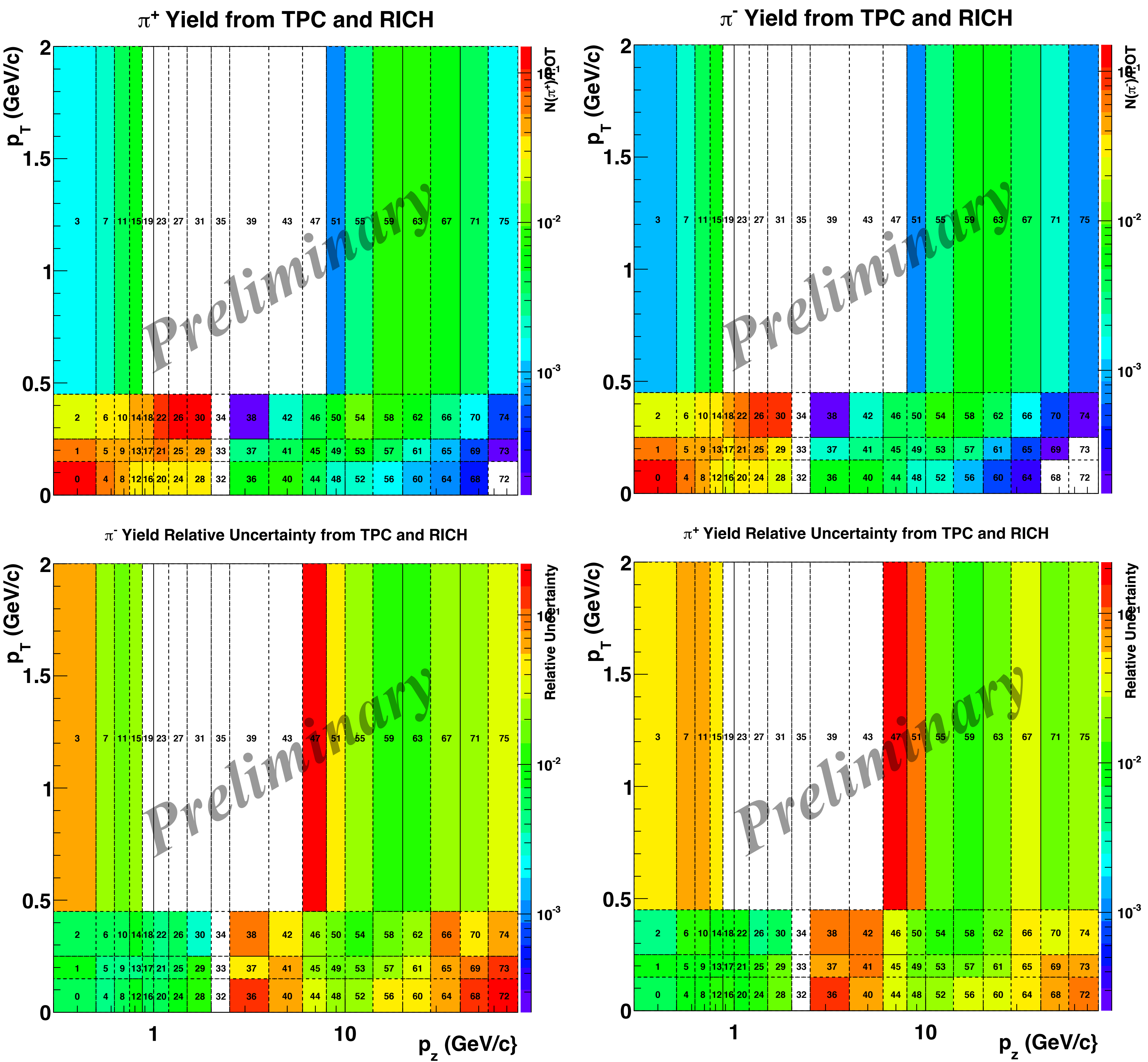
$$\sigma_{N_{\pi_i}}^2 = N_i + \bar{N}_i b_i^2 (1 + \bar{N}_i \delta b_i)$$

- Set $\delta b_i = 30\%$



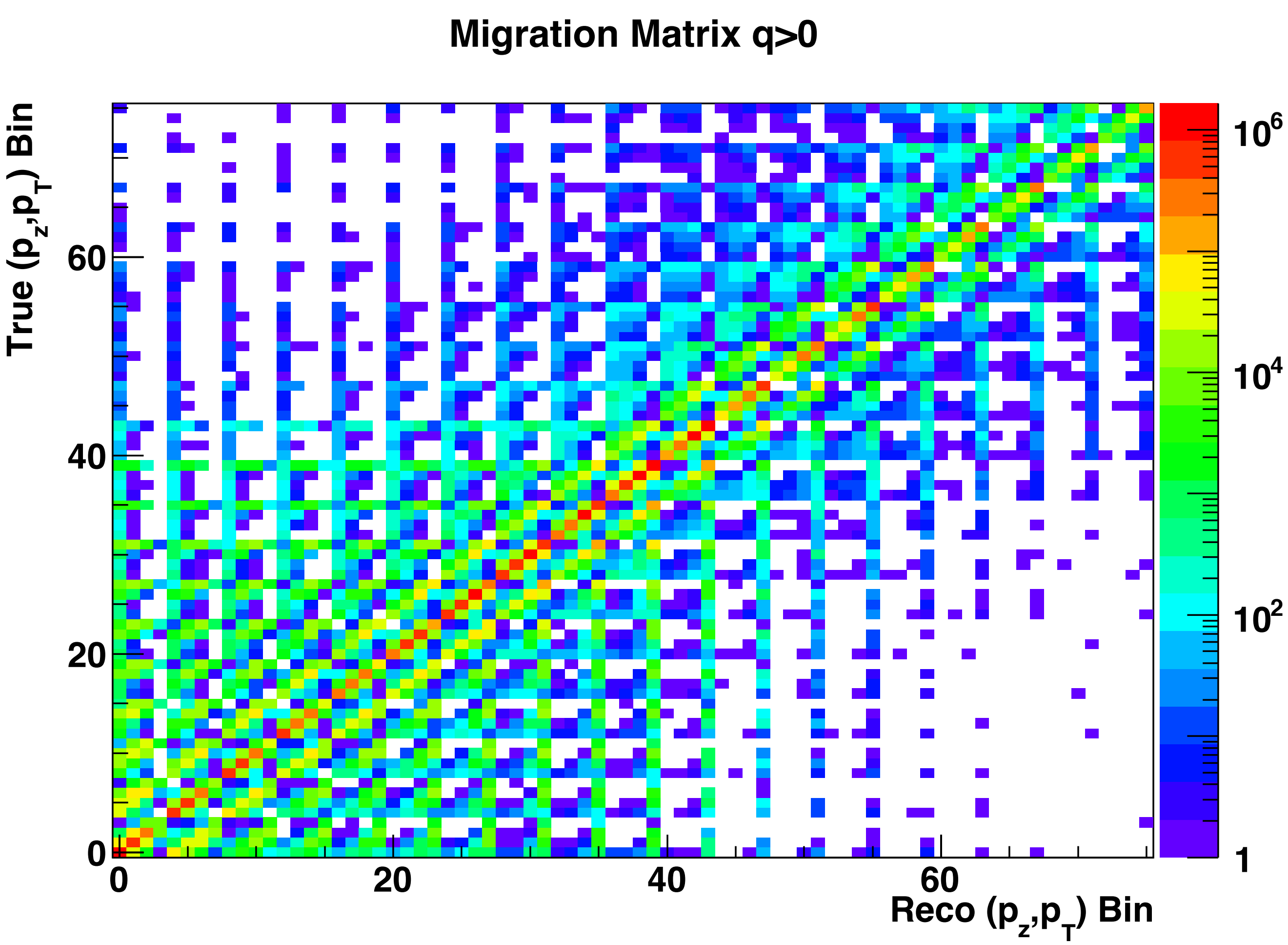
- MC is used to determine ranges for cut-and-count approach, as well as to estimate backgrounds in the 3 regions defined by the red lines.
- Error shown here is combined statistical and systematic (background subtraction).

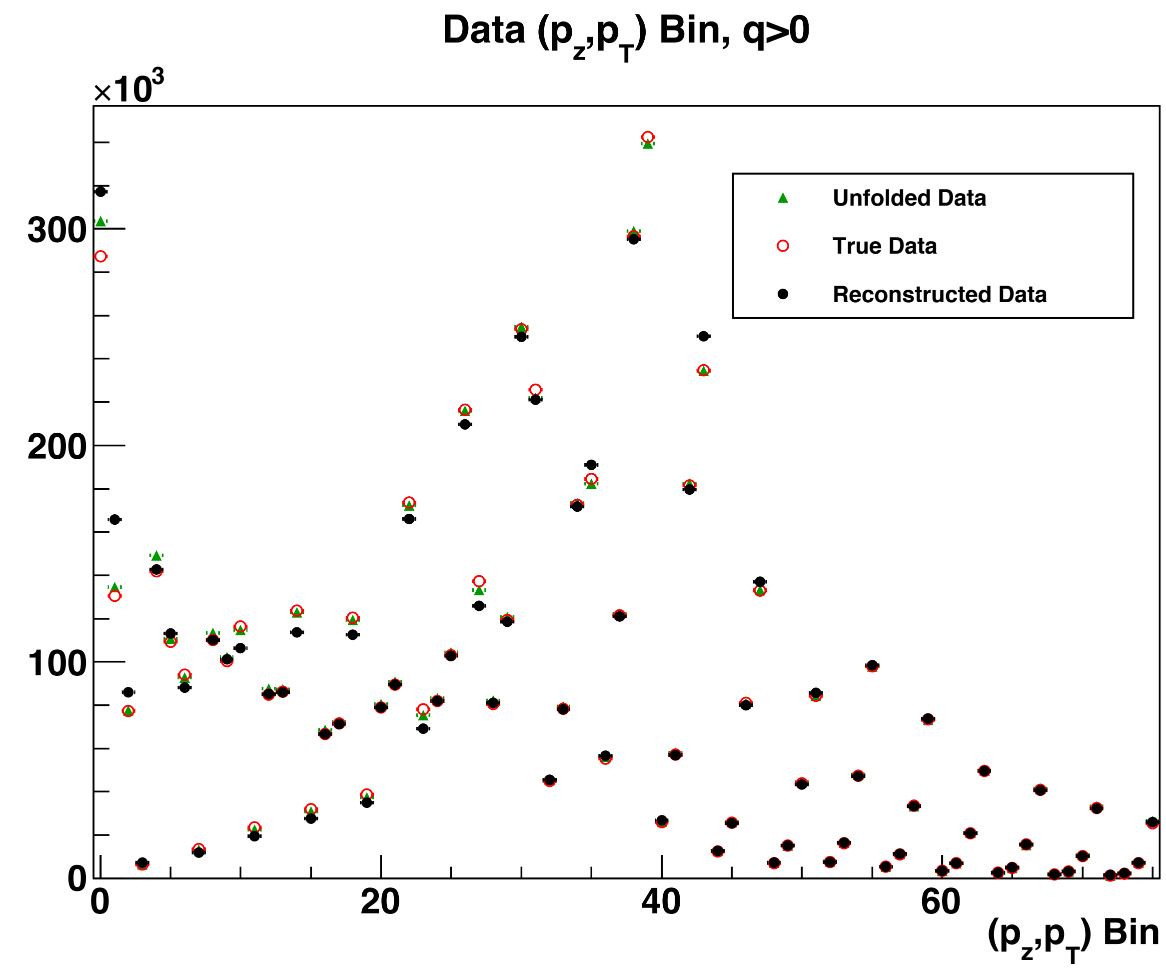
Uncorrected π Yields and Uncertainties



- Uncorrected for acceptance, etc.
- Uncertainties are combination of statistics and systematic of contribution from non-pion background
- Relative uncertainties are mostly < 10%
- Uncertainties > 10% dominated by statistics.

Reco → True Unfolding





- Make use of Root's TSVDUnfold
- Assume that $N(p_z,p_T)_i^{Reco} \rightarrow N(p_z,p_T)_i^{True}$ is good approximation for $N(\pi)_i^{Reco} \rightarrow N(\pi)_i^{True}$
- MC study shows that true and unfolded distributions agree to within 1%.

Summary

- MIPP collected several millions of events of π, K and p beams at various momenta incident on various targets, 1.6 x 10^6 120 GeV protons on an actual NuMI target.
- All MIPP sub-detector systems have been calibrated and the MC tuned to the data. MC/Data PID agreement looks reasonable, but some further fine-tuning is needed.
- Most pieces of the analysis of the NuMI target data are in place for measurement of pion yield across a very broad range of momenta from ~0.5 - 80 GeV/c (> 60 bins of (p_z,p_T)).
- Typical statistical uncertainty in each bin of (p_z,p_T) is <10%
- Systematics still need to be assessed, but expected to be well below 10%
- Plan to also determine kaon production above 20 GeV/c
- Promising independent K^0_s analysis underway (Amandeep Singh)